

BIG IDEAS 2016

EVERYTHING YOU NEED TO KNOW FOR THE YEAR AHEAD

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EXCLUSIVE

THE LAST FIGHTER PILOT

AIR WAR,
THE F-35,
AND THE
INEVITABLE
RISE OF
DRONES

→ Pilots wearing the new F-35 helmet can see through the plane—real X-ray vision!

7

AMAZING
(SLIGHTLY INSANE)
PROJECTS

+

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THE NFL'S BIG
PROBLEM

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Beginning this issue, *Popular Science* will be bigger and better than ever. Starting now, you can look forward to more editorial pages each issue, more original photography, more bold design and data visualization, and more in-depth feature articles. It's still the *Popular Science* you know and love—just more of it.

To create this new *Popular Science*, we are changing our frequency. Instead of publishing monthly, we will publish a larger, thicker issue bimonthly, so subscribers will get one expanded issue every other month. Each expanded issue will be like getting two issues in one. In the future, an annual subscription will contain six bimonthly issues. For more about the exciting changes, read the letter from Editor-in-Chief Cliff Ransom in this issue.

As always, our Customer Care Center is available to answer any questions you may have about your subscription. You may contact them at popsci.com/cs or, if you prefer, **800-289-9399**. We also have prepared a Frequently Asked Questions page at popsci.com/FAQ.

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REASON
#32

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The Future of MONEY

Currency has gone from cows to coins to paper to plastic. The next big disruption? We could all end up spending digital dough.

KASHMIR HILL



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BIG IDEAS OF 2016

Every year is a big one in science and technology. But 2016 will change the way we explore, connect, cure disease, and go to war. Here are the ideas and individuals poised to shape the year ahead.

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The new F-35 Joint Strike fighter jet is so sophisticated, so automated, and so connected, it's fueling a debate: Do we still need pilots to fly?

KEVIN GRAY

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F. SCOTT SCHAFER
ERIK SOFGE

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BARRY YEOMAN

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Air Force Lt. Colonel
Rhett Hierlmeier,
Photograph by
Spencer Lowell





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New Year, New Era

For nearly 144 years, *Popular Science* has arrived at your doorstep, in your mailbox, or on your newsstand just about the middle of each month. Starting with this issue, we'll be doing things a bit differently. Instead of monthly delivery, *Popular Science* will begin offering bigger, richer magazines every other month.

This is, obviously, a big change—like once every 144 years—and it bears some explanation. When making a product, two of the most important questions you can ask are, “How are people using my widget, and have I optimized for that case?” The engineers, entrepreneurs, and designers we cover ask these questions regularly. We thought it only right to ask them ourselves.

What we found is that over the past few years, the way people use *Popular Science* has changed. Where readers once relied on our printed magazine as a source of news, they mostly go to our website for that today. That's why our online and social-media audience continues to grow so rapidly. What readers prefer from print—or so they've told us—is a richer experience, one filled with unique perspectives, creative and well-considered illustrations, and beautiful photography.

And therein the change in frequency: Rather than produce 12 smaller issues each year, we'll aim to make six bigger ones that afford the experience our readers desire. As you'll notice as you page through this issue, all of our sections have grown substantially, with more gadgets, incredible ideas, and amazing DIY projects than ever before. Our feature well has nearly doubled too. You'll see more original photography,



more data visualizations, more thought leaders, and more great stories. It's still your *Popular Science*—there's just more of it.

So that's the news on the print side, but as you can probably guess, that's only part of the plan. By far, the biggest area of growth *Popular Science* faces is in online publishing. (It doesn't take a futurist to predict that.) Changing our print frequency will allow us to redeploy resources to seize those opportunities. That will mean more news—we'll always be committed to covering what's new and what's next—but it will also mean dedicated digital features, new video franchises, and the flexibility to tell amazing stories with the coolest new technologies out there.

Whenever I tell people that I'm the editor in chief of a magazine that's been publishing continually since 1872, their first response is almost always, “Wow, that's so amazing!” Then they think about it for a moment and say somewhat more ominously, “Wow, you've really got a legacy to protect.”

The truth is, they're right on both counts. It is amazing to lead a historic brand, but it's also a challenge. When the world changes—as it has more than a few times in nearly a century and a half—you need to change with it. Just like the scientists and engineers in our pages, we need to look objectively at the future and embrace the disruption we so often cover. We need to trade orthodoxies for experimentation and fear for exuberance. And at every step, we need to keep our readers squarely in sight. So please join us for this next chapter. I think you're going to like what you find.

Enjoy the issue.

Cliff Ransom
Editor in Chief



Editor in Chief Cliff Ransom
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Editorial Interns Lydia Chain, Steph Lin, Nicole Lou

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Photo Director Thomas Payne
Digital Associate Art Director Michael Moreno
Designer Zachary Gilyard

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Online Director Carl Franzén
Senior Editor Paul Adams
Social Media Editor Jason Lederman
Assistant Editors Sarah Fecht, Claire Maldarelli
Producer Joey Stern
Contributing Writers Kelsey D. Atherton, Mary Beth Griggs, Alexandra Ossola

CONTRIBUTING EDITORS

Brooke Borel, Tom Clynes, Clay Diltow, Nicole Dyer, Daniel Engber, Tom Foster, William Gurstelle, Mike Haney, Joseph Hooper, Corinne Iozzio, Gregory Mone, Adam Piores, P.W. Singer, Erik Sofge, Kalee Thompson, James Vlahos, Jacob Ward

Group Editorial Director Anthony Licata

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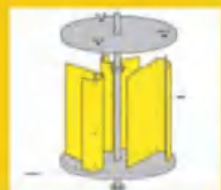


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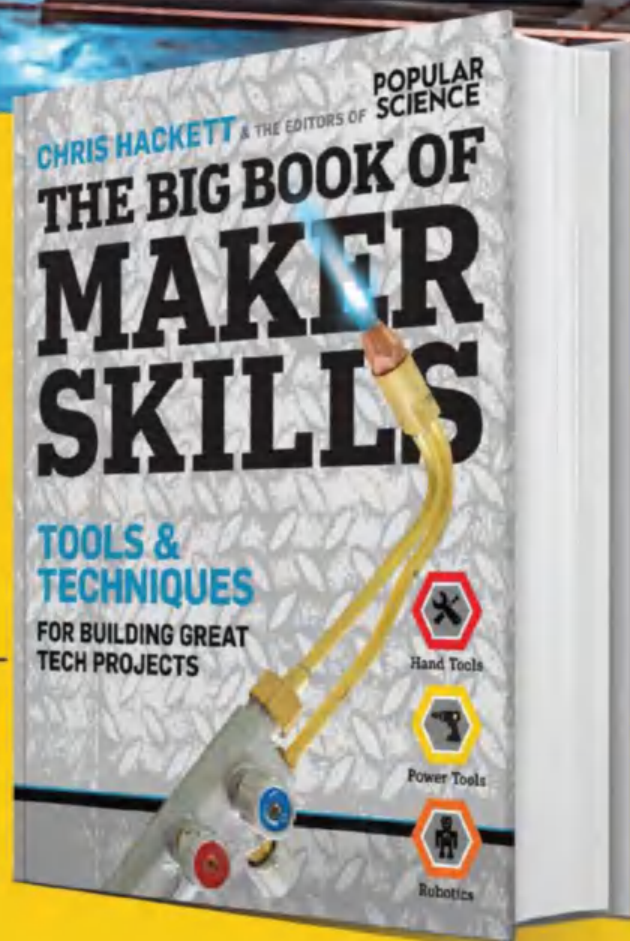


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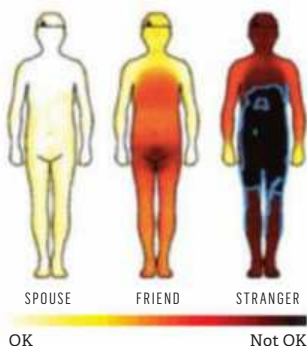
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Um, excuse me.

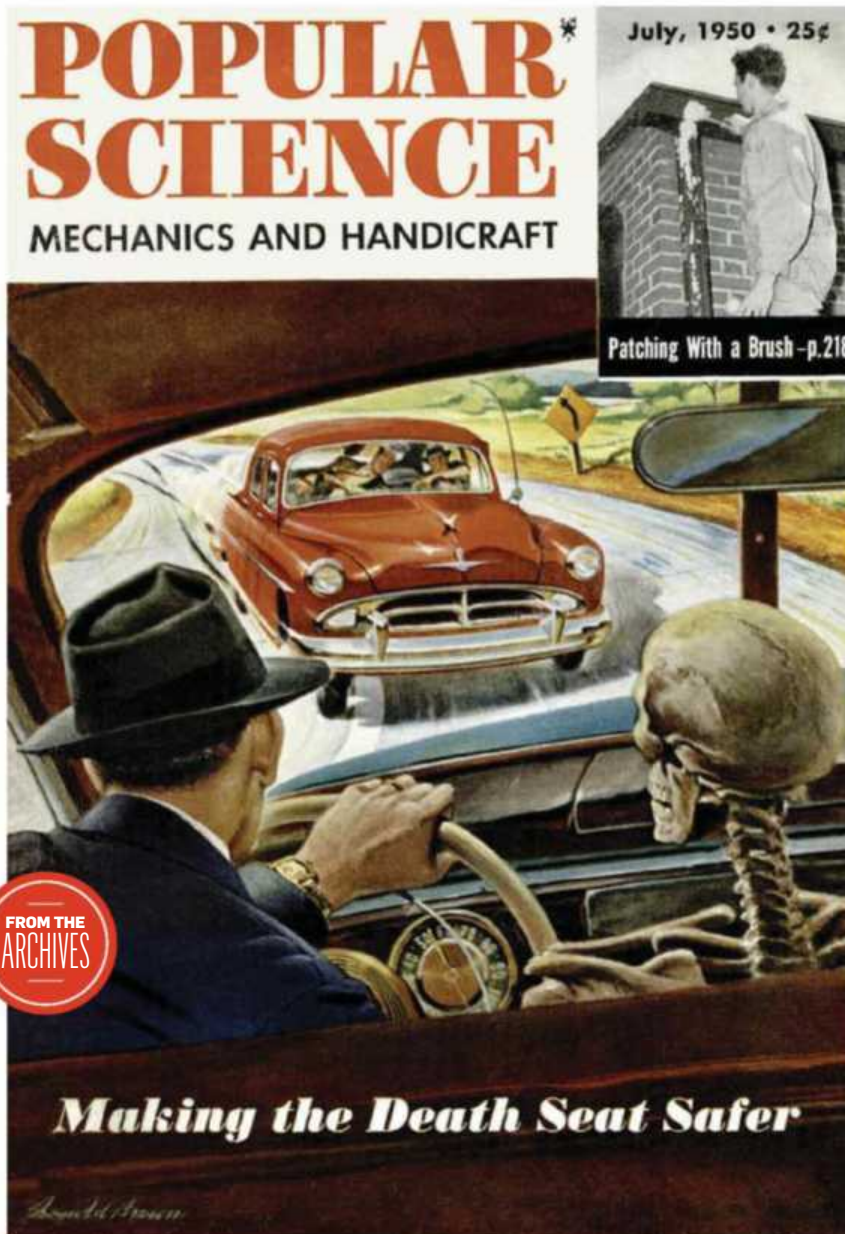
Winter inevitably means one thing to commuters: more people cramming onto trains and buses to travel in warmth. To help you navigate that socially awkward situation, scientists have created “touch-area maps” that show where it’s OK to make contact with others—and where it isn’t. Check out pops.ci/touch to see why where you live matters too.

Podcast Finale!

Already planning your 2016 vacations? Don’t miss this season’s final episode of *Futuropolis*. It explores the future of travel, and promises to take you to the location of your high-tech digital dreams.



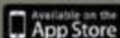
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The Early Science of Car Safety

JULY
1950

Sixty-six years ago, World War II was in the rearview mirror, and the economy was doing well. But the rise of the auto industry brought with it a new concern: traffic deaths. Safety engineers referred to the passenger seat as the “death seat”—a metaphor we took even further. “Death never takes a holiday,” we wrote. “He rides in every car, every day, with his bony finger on the right front seat.” Fortunately, we also had a positive spin: technologies being developed to protect car passengers, including “the Thin Man”—an early 2-D version of the test dummy—and seat belts, which did not automatically come in cars at the time.



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Now

EDITED BY MICHAEL NUÑEZ + XAVIER HARDING

JANUARY/FEBRUARY 2016



INSTALL YOUR OWN THEATER

LG TV EG9600
\$5,000

If you've ever set eyes on an organic light-emitting diode television, the benefits are obvious: They're thinner, brighter, and have sharper contrasts than any other TVs on the market. LG's newest version—the EG9600—is the pinnacle of this display technology: It offers a near-perfect picture quality because OLED pixels don't leak light, meaning blacks are blacker and colors don't wash out. In addition, the picture holds up even when viewed from the sharpest angle, so even latecomers to the party will have a view of the on-screen action.

by
**DAVE
GERSHGORN**

LISTEN LIKE A PRO

①

MARANTZ AV8802A AND MM8077

\$4,000 PREAMP
\$2,400 AMPLIFIER

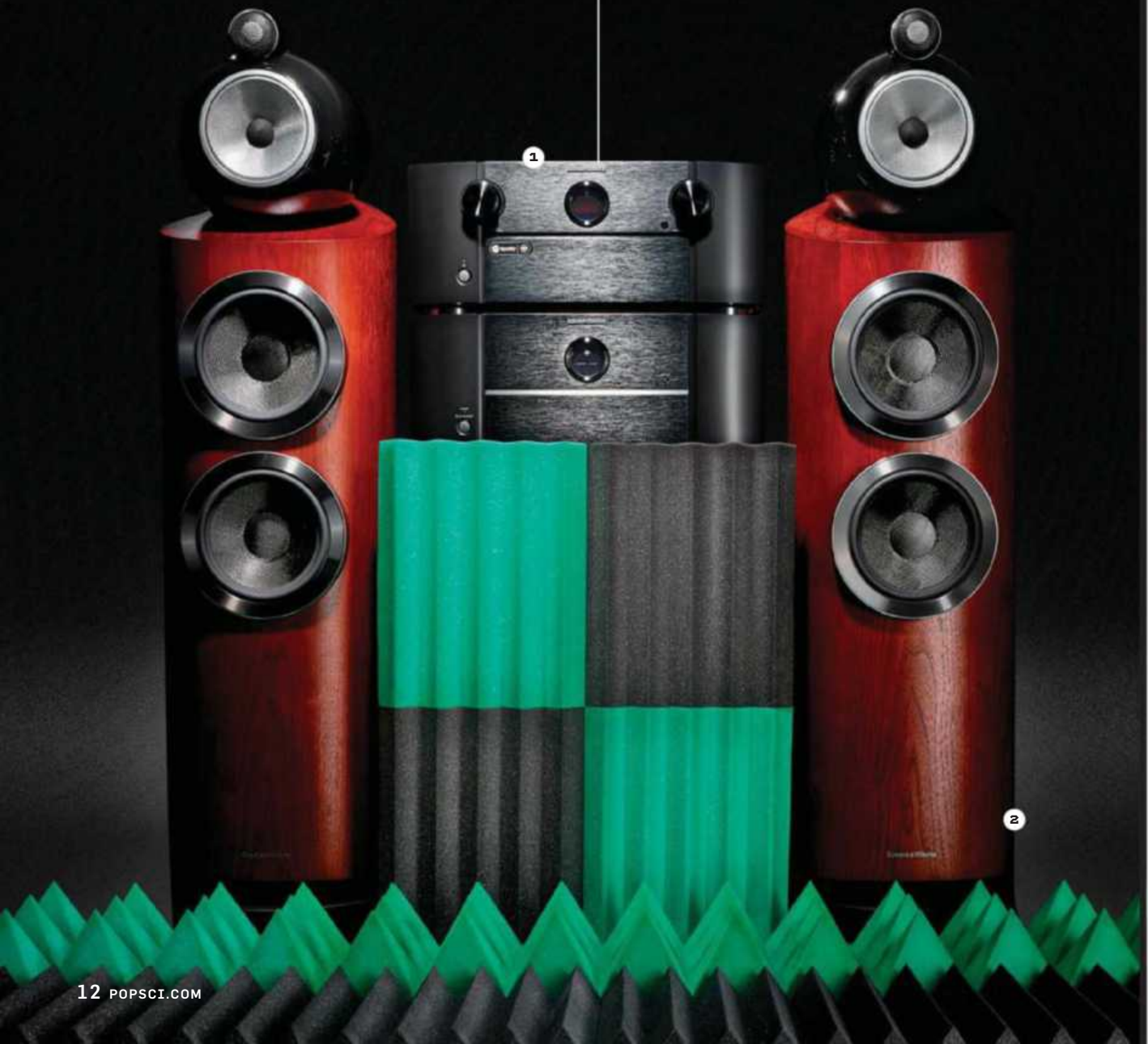
This combination Marantz preamp and amplifier can drive up to 150 watts to seven speakers at a time. It's among the first systems to process ultra-high-definition 4K through HDMI. It also supports Dolby Atmos—theater-quality audio that places you in the middle of a three-dimensional soundscape. You can also stream your favorite Pandora, Spotify, and SiriusXM satellite radio channels directly to the units.

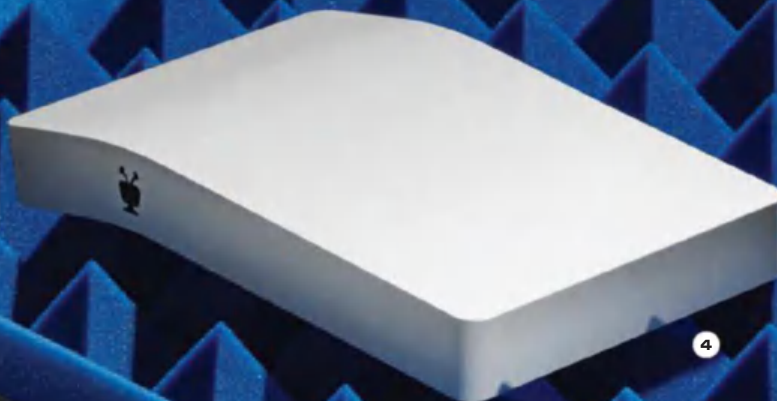
②

B&W 803 D3 SPEAKERS

\$17,000

Bowers & Wilkins spent eight years perfecting the 803 D3 Diamond series design, and it paid off. The 803's birch casing is specially configured to minimize unwanted vibration and deliver high-fidelity audio. They might appear bulky at 4 feet tall and almost 2 feet deep, but each 144-pound speaker packs a mean punch. Each one comes loaded with two 7-inch subwoofers, a 5-inch midrange driver, and a 1-inch synthetic diamond tweeter that makes every sound crystal-clear.





4



3



1

1

GOOGLE ONHUB \$200

The best house parties mean a lot of people posting updates to Twitter and uploading pictures. That can cause a traffic jam on your Wi-Fi. With Google OnHub, you can set one high-speed 5 GHz network for just your devices, and a 2.4 GHz password-protected network for your Instagramming friends. It's like having two digital highways running through your living room.

3

XBOX ELITE WIRELESS CONTROLLER \$150

Serious gamers are known to abuse their controllers. So Microsoft built the ultra-durable Xbox Elite Controller. It uses stainless-steel thumbstick shafts that never wear out. Plus, it can be completely customized: The joysticks and directional pad can be changed for comfort, and four removable paddles on the rear can be programmed for more-efficient in-game maneuvering. Your *Call of Duty* enemies won't know what hit them.



2

2

SLINGBOX M2 \$200

There's the big TV in the living room, but what happens when you're making wings in the backyard? The Slingbox M2 lets you take the game to the grill, on an iPad in the basement, another TV in the bedroom, or even on your phone in the bathroom.

4

TIVO BOLT FROM \$300

The disparate worlds of streaming and cable services are finally together in one device. The Bolt lets you search every channel and video service to find the exact show you're looking for, and skip commercials with a press of a button. Plus, it can record live TV.

MASTER YOUR DOMAIN

DESIGNING THE ROBOT NEXT DOOR



by
**LINDSEY
KRATOCHWILL**

When NASA's *Sojourner* rover landed on Mars in 1997, Cynthia Breazeal remembers thinking, "We can send robots to space, but we still don't have ones that can 'live' beside us." What's up with that? She set out to find the answer, and in the process, pioneered the field of social robotics. This spring, Breazeal will begin shipping Jibo, the world's first companion bot for the home, and the pinnacle of her 18-year endeavor. Breazeal recently spoke to *Popular Science* about how robots will become family members, guarding the home, and reading us bedtime stories.

read stories to your children, it can be a learning companion for your children, it can help you maintain an exercise program.

How did you get into robotics?

The first time I really became aware of robots was when I saw *Star Wars*. I was 10 years old, and I was in the theater. Seeing R2-D2 and C-3PO—that was really the moment. I just fell in love with them.

people's expectations, we must understand how people interact with new technology. We've learned that our brains intuit robots as creatures. Now, we are exploring how people interact with autonomous robots. That's social robotics—the field I'm credited for pioneering.

It seems like we should have seen a companion robot by now.

Until recently, roboticists haven't been focused on building robots for nontechnical people. It's

How is Jibo different from other robots?

The robotic products today are designed to do only one thing. For example, when you buy a Roomba, it's a vacuum, and that's all it does.

Why is this possible only now?

Because of mobile devices: Processor speeds, networking speeds, battery life, display technology, sensing technology—all of these things continue to increase in capability while prices decrease. With that, things like speech recognition, cloud computing, and machine learning have been maturing as well. These are all part of building a sophisticated social robot.

"Jibo is a community experience. It can look at me and my kids. We can use Jibo together. It's not competing for our attention."

Do our homes really need more gadgets?

Jibo is a community experience. Jibo can look at me and talk to me, and look at my kids and talk to my kids. We can use Jibo together. We don't have to feel like there's something competing for our focused attention the way a phone screen does. We can have a group dynamic, and you still are engaged with the people around you. You're not pushing people away, the way that our current devices do. It's a very different experience.

almost like when the computer industry was building really big, expensive computers that only experts could use. Eventually, people started thinking about putting a computer in every home so anyone could use it. It's the same challenge, building a robot everyone can operate.

We've positioned Jibo as a versatile companion, one that offers utility with the warmth of a meaningful interaction.

How do you begin to solve that problem?

In order to design robots that match

What exactly can it do?

Jibo is a platform. Developers can build applications using any of Jibo's features, including voice-recognition software, cameras, and touchscreen. So Jibo can be a photographer, it can help with home security, it can

Do you see a Jibo in every home?

Yeah, of course that's the goal. In the same way that, back in the day, the goal of every PC business was to put a computer on every desk, our goal is to put a social robot in every home. And I think the way that our smartphones and laptops are already ubiquitous, social robots are going to be ubiquitous soon.

Now

The Platform



Trending

1

NORTH FACE SUMMIT L4

North Face makes a lot of great down jackets. This isn't one of them. In this one, the company used springy polyester balls of synthetic insulation to mimic the shape of down. The balls trap heat like down plumes and feel nearly as plush. **\$299**

2

PATAGONIA FITZ ROY DOWN PARK

This glossy jacket uses sustainably harvested down stuffed into a nylon shell with a water-repellent finish. Insulating fabric uses interlocking Y-shaped fibers to repel water better than straight threads. **\$449**

JACKETS THAT CAN WEATHER A STORM

Nothing compares to goose down when it comes to keeping you warm. The only problem is when you wear down in the snow or rain (or sweat in it), it flattens into a soggy bag of feathers, losing its ability to insulate. These five puffy jackets were designed to stay warm no matter how damp it is outside. Here's how:

by
BERNE BROUDY

3

OUTDOOR RESEARCH DIODE HOODED JACKET

A jacket's hood, shoulders, forearms, and waist take the brunt of a storm. This one uses an artificial filling over those areas, so it won't compress even when it's soaked through. The chest also uses a mix of 70 percent water-repellent down and 30 percent artificial filling to trap in heat. **\$325**

4

BLACK DIAMOND HOT FORGE HYBRID HOODY

Black Diamond used a clever mix of materials to keep this jacket fluffy and dry. It inserted plastic fibers into down clusters at the microscopic level, propping them open even when they're wet. There's no weight penalty for the mixed material either, so the jacket is always easy to stash. **\$249**

5

RAB ELECTRON

Rather than mixing materials, Rab treated each down cluster with a water-repellent coating. The result is a down filling that's able to maintain its fluffiness even in damp conditions. The coating also protects it from microbes that can break down the feathers over time and reduce your jacket's useful life. **\$325**



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I PLUNGED INTO FREEZING WATER

—And Survived to Tell the Tale

When a ship sinks at sea and you're thrown into the water, hypothermia sets in quickly, so every second counts. An immersion suit is designed to buy you time. Constructed like a surfer's wetsuit, it keeps you warm for up to three to six hours, until help (hopefully) arrives. Smart sailors and fishermen carry them and, when on a boat, so should you: Even a plunge into 50-degree water will induce hypothermia within 60 minutes.

But what if help is a long time coming? The Stearns I950 ThermoShield 24+ bills itself as the most advanced immersion suit made, one that can extend that crucial in-the-water survival window up to 24 hours, and keep you alive even in freezing (32°F) water. How good is this suit? I couldn't leap from an arctic charter to test its outermost limits at sea. But I was able to try it in northern Vermont, in early November, with snow falling, and the water in Lake Champlain hovering at that 50-degree mark. So here's what I did.

I went down to the dock, lifted the suit's neoprene one-piece over my body, and threw myself in. I immediately bobbed to the surface and floated. The suit has enough buoyancy to support 330 pounds. (Let's just say I'm about a third of that.) A large air pillow **1** on the rear of the suit naturally oriented me to float on my back. Breathing into a valve on the right shoulder **2** fills the air pillow. Breathing into a valve on the left shoulder circulates warm breath around the core **3** (to protect vital organs), and then arms, hands, feet, and legs.

The hood blocks sound, **4** so I couldn't do much but look at the clouds. More tube breathing made me warmer



In addition to staving off hypothermia, the suit is fire-resistant. Thankfully, our reporter didn't have to dodge any flaming wreckage.

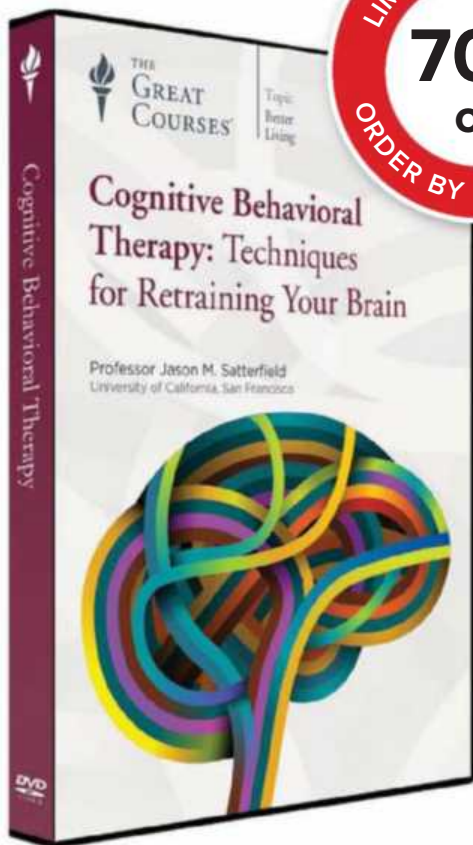
and more buoyant. My fingers got wet because I didn't cinch the suit's wrist straps. **5** Those fingers got cold fast. But the suit's designers foresaw this problem: Jam your hands in the hand warmer **6** sewn onto the stomach, then back into the gloves, and they stay as warm as need be.

I floated like that for an hour, just long enough to (theoretically) get hypothermia. But I was fine. I had, however, floated several yards from shore, and swimming back was awkward: I managed a floundering backstroke back to the dock. While I am sure I could have floated all night, I'm glad I didn't have to.

by
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HIT LIST

10 Great Ideas in Gear

1 TELESIN UNDERWATER GOPRO DOME PORT

Underwater photography is cool. Telesin makes it cooler. This GoPro case uses a dome made of acrylic to create space between your lens and the water—allowing for a more visible waterline when simultaneously shooting below and above surface level. **\$85**

2 AERELIGHT A1

Fluorescent desk lamps are harsh on the eyes. This one uses organic light emitting diodes (OLED) to provide a warm glow. The lamp can be turned on and off with a tap anywhere on its body and offers three brightness levels. Qi inductive charging built into the base lets you easily charge some phones. **\$300**

3 RIF6 CUBE MOBILE PROJECTOR

Cube isn't much bigger than a smartphone. But the pocket projector produces a big picture. Its battery recharges over micro-USB, meaning one fewer cable to trip over during movie time. **\$300**

4 JAMSTIK+

The Jamstik teaches you to play guitar, and any song note by note, with a 16-inch-long guitar and 3 apps. GarageBand pairing lets you record your creations. One step closer to rock-star status. **\$300**

by
**XAVIER
HARDING**

5 EMBER SMART MUG

Control your coffee's temperature using the dial on the mug's base or via smartphone app. An LED indicator near the bottom offers precise temperature readings for a drink that's not too hot and not too cold—satisfying your inner Goldilocks. **\$129**

6 SATECHI USB TYPE-C 3-IN-1 COMBO HUB

If you're photo or video editing on the go, you need this adapter. It turns one USB Type-C port into three USB 3.0 ports, an SD-card slot, and a micro-SD-card slot. **\$35**

7 PAKPOD TRIPOD

Outdoor gear needs to be durable. The weatherproof Pakpod gives photographers a stable yet rugged tripod for cameras. Stakes at the bottom make sure it stays put. **\$99**

8 ONEWHEEL

Want to balance-board off-road? The all-terrain go-kart tire on this self-balancing electric vehicle lets you. It reaches 15 miles per hour, making it faster than most other electric balancing boards. **\$1,499**

9 MOPHIE SPACE PACK

iPhone owners want more storage and a better battery. The Space Pack improves both. It adds 32GB, 64GB, or 128GB of added space. Plus it roughly doubles your battery life. **From \$150**



10 APPLE IPAD PRO

Apple called on the king of all planets, Jupiter, when announcing its latest tablet. And rightfully so. At 12.9 inches, the iPad Pro is the biggest iPad yet. There's enough room to edit 4K video and to work in AutoCAD, and with full support for the company's Pencil stylus, Apple wants professionals to use this for their great creations on the go. **From \$800**



CLOCKWISE FROM TOP LEFT: COURTESY TELESIN; COURTESY AERELIGHT; COURTESY CUBE; COURTESY EMBER; COURTESY JAMSTIK; COURTESY MOPHIE; COURTESY PAKPOD; COURTESY SATECHI

PIXEL-PERFECTION

A NEW BREED OF TELEVISION

LG has created a brand new category of TV with the introduction of OLED and its emissive technology, **Organic Light Emitting Diodes**. These organic substances are self lighting and glow when an electric current runs through them. This innovation allows for each sub pixel to be individually lit and turned off or on as needed to create an ideal viewing experience.



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OFF CREATING
PERFECT BLACK

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The exceptional picture quality holds up even from wide viewing angles, so don't be afraid to load up the couch.

IMPOSSIBLY THIN DESIGN:
OLED technology enables a design that is ultra-thin and light. It's supremely elegant, and as lovely on a tabletop as it is wall-mounted. Available in both flat and curved models.

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A MOTORCYCLE LIKE NO OTHER

HONDA PROJECT 2&4

What happens when you combine a car and a motorcycle? Honda decided to find out when it pitted more than 80 of its brightest engineers against each other in its annual Global Design Project, an internal competition to foster exchanges among its global network of design studios. The rules of the contest were simple: Take a V-4 motorbike engine, and put it on four wheels. The goal was to build

something fun and thrilling. Honda wanted engineers to combine the stability and handling of a racecar with the driving experience of a motorcycle—almost like a supercharged go-cart.



Beneath the panel on the right side of the vehicle are two hidden brackets, so it's easy to slot in a passenger seat.



The winner is this single-seat, bike-and-car hybrid called the Honda Project 2&4, designed by Martin Petersson from a Honda motorcycle R&D center in Asaka, Japan. The Project 2&4's floating seat means drivers will feel the wind blowing across their body, while the motorcycle-grade suspension, engine, and featherweight 890 pounds offer quick turns. Bonus: Because the steering wheel and pedals can easily be flipped from one side to the other, drivers around the world can customize their experience based on their track or country.



Powered by a 212-horsepower Grand Prix motorcycle racing engine, the 2&4 was built for speed.

by
ERIC ADAMS



HOW TO BE A YOUTUBE STAR

(featuring MKBHD)

A lot of 22-year-olds have opinions about gadgets. Not many have 3 million fans who will listen. Marques Brownlee—best known as MKBHD—is an Internet celebrity who's attracted hordes to his YouTube channel since launching seven years ago. Brilliant and funny smartphone reviews, unboxings, and meditations on all things tech have set him apart as one of the most influential tech vloggers out there. Here, we unbox his tools of the trade.

TIPS FROM MARQUES

LEARN FROM THE BEST

"When I see a shot in a video or movie I like, I'll Google it to find out what it is and how to do it. I watch a lot of YouTube tutorials. The more often I do it, the more steps I remember—and the easier it gets."

SHOOT FOR THE EDITOR

"At events I'll make a list of everything I want to capture, shoot it, and then record audio back at my hotel since it's a more controlled environment. I film knowing what type of effects I want to add afterward."

SPEAK TO WHAT YOU'VE FILMED

"I have talking points to make sure I don't forget anything important. It's more of a conversation than a script. If I fully scripted videos, I would never finish anything on time."

4 RED WEAPON DRAGON

Red's cameras aren't cheap. But they offer user-upgradeable shooters that record in 6K—the highest resolution available. **\$59,500**

5 SIGMA 18-35MM F/1.8 LENS

Sigma's lenses are sharp. Crystal-clear capture with great low-light options. **\$799**

1 YAMAHA HS8

Engineers trust Yamaha's studio monitors to deliver precise sound across all frequencies. Never underestimate good audio. **\$499**

2 ASUS PA328Q

This newer model of MKBHD's monitor offers better ergonomics, a 4K pixel count, and precise color accuracy to easily spot errors. **\$1,299**

3 APPLE MAC PRO

YouTube supports up to 4K video, but Apple's tower PC has the horsepower for three 5K screens at once. Hashtag futureproof. **\$2,999**

6 SOUND DEVICES MIXPRE D-P48

This battery-powered field mixer can be used as a preamp to add clarity when filming. Or afterward to dub over mistakes. **\$929**

7 SENNHEISER MKH416

Cutting out ambient noise is key. This shotgun mic picks up audio only where it's aimed, so your viral video will sound just how you like. **\$1,249**

8 LOGITECH MX MASTER MOUSE

The side wheel on this mouse lets you scroll horizontally as easily as vertically. Pair three devices at once, switch connections with a button press. **\$99**

by
XAVIER HARDING

WANT MORE? Go to popsoci.com/mkbhd for the full interview.

Next

EDITED BY BREANNA DRAXLER + MATT GILES

Something bizarre is happening to KIC 8462852, a star located 1,480 light-years from Earth. Its glow dims significantly and at irregular intervals. The cause could be asymmetry in the star, or it could be the shadow of a family of comets, for example, or a megastructure built by an advanced civilization. SETI's Allen Telescope Array recently searched the skies to no avail, so this spring, scientists plan to investigate using the Green Bank Telescope. It is far more sensitive than the array and is equipped to scan 1.5 billion radio frequencies simultaneously. If the object is built, we might be able to detect radio signals,

like those of earthly electronics, from its makers. Whatever Green Bank reveals (we're hoping aliens), it will be new to science.

by
SARAH FECHT

The time lapse of the Green Bank Telescope consists of 400 images captured over a period of three hours, starting at 9 p.m.

WHAT HAVE THEY FOUND? Check out popsci.com/KIC for updated reports.

328

Diameter, in feet, of the Green Bank Telescope, the world's largest fully steerable radio telescope



MIND- ALTERING DRUGS CAN CURE PTSD

MDMA releases neurotransmitters, such as serotonin and dopamine, in the brain.

During the course of a given year, approximately 5.2 million adults in the U.S. will experience PTSD.

We just need to reimagine the trip

Post-traumatic stress disorder in the U.S. has reached crisis levels. About 8 percent of Americans experience PTSD; for veterans, that number is 30 percent. Treatment is notoriously difficult, but people could find relief in an unusual form: psychedelic drugs.

MDMA—found in molly and ecstasy—earned a bad rap in the 1990s as ravers' drug of choice. But psychotherapists are coming to value the way it increases empathy while decreasing fear and defensiveness. "MDMA gives people the ability to revisit an event that's still painful without being overwhelmed," says psychiatrist Michael Mithoefer. Following a recent MDMA trial, 83 percent of his treatment-resistant participants no longer showed symptoms of PTSD.

In one study, Mithoefer worked with a New York City firefighter post-9/11. The subject had tried treatment before. While undergoing a popular method that uses eye movement to reprocess a trauma, he'd been so overcome that he ripped a sink off the wall. MDMA, however, worked. "It wasn't easy for him," Mithoefer says. "But our sink is still attached."

MDMA isn't a one-trick pony either; it can treat end-of-life anxiety and alcoholism, and it's not addictive. "We're talking about the rise of a whole field of medicine," says Rick Doblin, founder of the nonprofit Multidisciplinary Association for Psychedelic Studies, which is running a handful of MDMA trials, including Mithoefer's. Doblin thinks the FDA

will greenlight the drug for mainstream use by 2021: "The psychedelic psychotherapist of the future will have a medicine bag filled with drugs like MDMA."

by
MATT GILES

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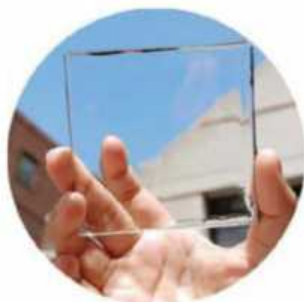
-Dennis Cordova, Amateur Metalworker



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SOLAR PANELS FOR EVERY SCREEN

Instead of searching for an outlet to keep your phone alive, what if all you needed was some sunshine? An MIT startup has created a transparent coating that transforms surfaces into solar panels. **N.L.**

THE TRICK

Typically solar panels soak up photons from the sun's rays and convert them into electricity. The panels tend to be dark, because the darker a material, the more visible light it absorbs. The idea of transparent panels would usually get dismissed because they don't, by definition, absorb any visible light—it just passes right through them.

THE TECH

Ubiquitous Energy, a spinoff of MIT, has created a coating made of organic molecules that absorb the sun's ultraviolet and infrared rays. Since the light isn't in the visible range (for humans), the coating appears clear. The material doubles as a semiconductor: When photons hit the surface, they excite electrons that flow as an electrical current to power the device.

THE TAKE-AWAY

"You can put the coating on anything and turn it into an electrical source," says company founder Miles Barr—smartwatches, phones, windows, or even cars. When the tech is mature, Barr anticipates it will convert solar energy into electricity with 10 percent efficiency—two-thirds the industry average. Who doesn't want an excuse to spend more time at the beach?

A Building That Eats Smog

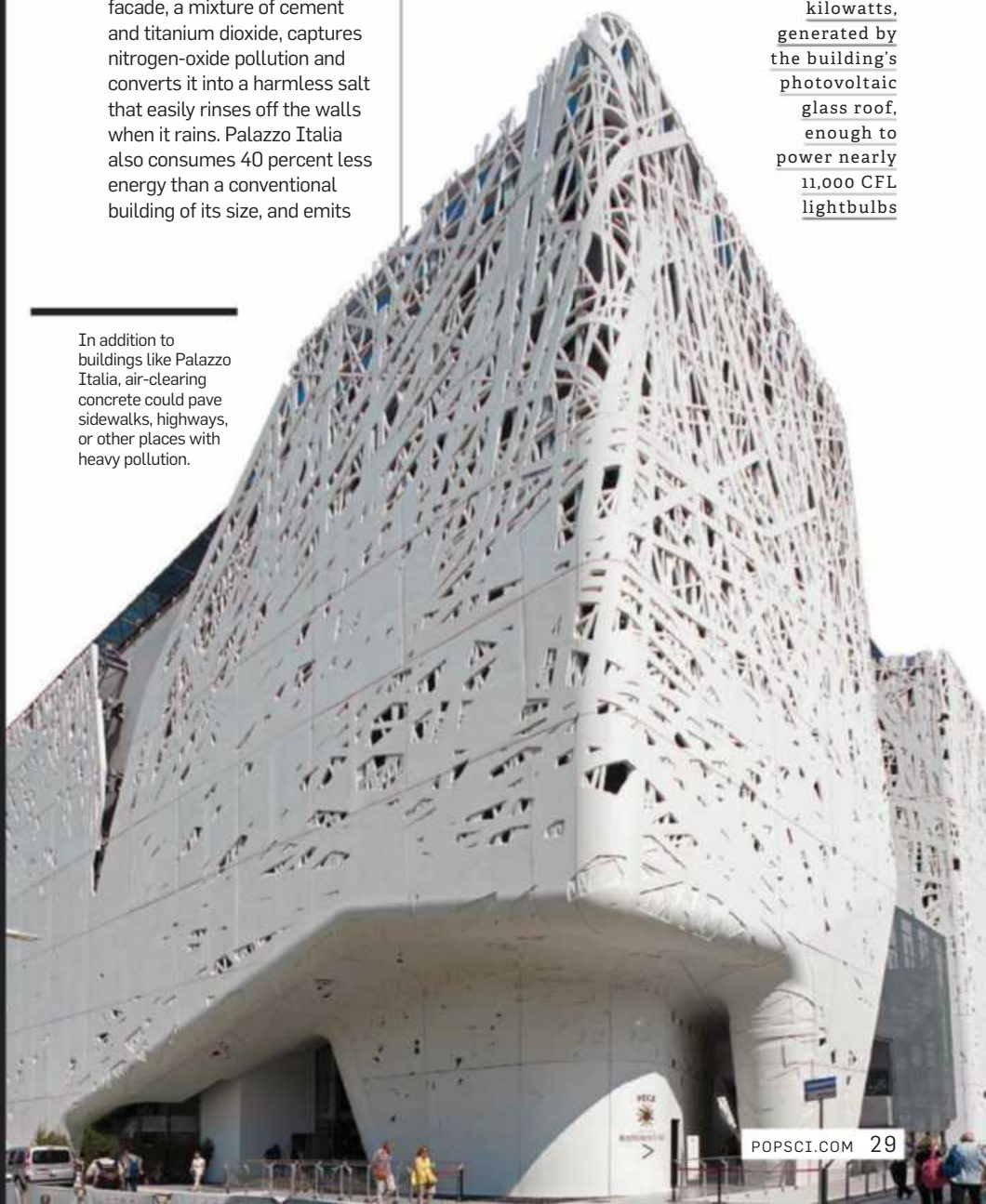
A new construction material could make the concrete jungle function a bit more like a natural one. Palazzo Italia, which debuted at the 2015 World's Fair in Milan, is the first building made of concrete that's designed to clear the air. The facade, a mixture of cement and titanium dioxide, captures nitrogen-oxide pollution and converts it into a harmless salt that easily rinses off the walls when it rains. Palazzo Italia also consumes 40 percent less energy than a conventional building of its size, and emits

zero air pollution. "We wanted the building to be an osmotic organism," says lead architect Michele Molè—like a tree that breathes in carbon dioxide and exhales oxygen. **NICOLE LOU**

140

Energy, in kilowatts, generated by the building's photovoltaic glass roof, enough to power nearly 11,000 CFL lightbulbs

In addition to buildings like Palazzo Italia, air-clearing concrete could pave sidewalks, highways, or other places with heavy pollution.



Let's Talk About Love in the App Age

It still includes 🍌🍌🍌🍌🍌*

*long walks on the beach

Christian Rudder,
co-founder of
OkCupid and author
of *Dataclysm*

"I don't think dating or sex is any different than it's ever been. It just happens to have this new interface."

Photograph by
**MARIUS
BUGGE**

People today are busy. As a result, they're staying single longer, and they're more and more connected to their devices. In some ways, technology enhances human interaction.¹ Smartphones and laptops have changed how we communicate with almost everyone: our moms, our cat-sitters, and even our best friends from grade school.² They have certainly changed whom we have sex with and date.³

1 "Technology mediates all of our relationships, operating through shared pictures, texts, even emojis."

2 "We can now be social with screens in ways we never could before. But chatting online is a supplement, not a substitute, for meeting face to face. We mistake that at our peril."

3 "Snapchat has become an incredibly popular way to flirt. People feel they can communicate with images in ways they can't with words."

4 "Think of online dating sites as introduction services. The best way to use these technologies is to let them make the person-to-person connection happen more quickly."

5 "With traditional sites, like Match.com, dating can feel like a second job. Tinder, on the other hand, turns online dating into more of a game."

6 "The Internet has made people and ideas more disposable, whether romantic or any other

“Show me the history of any new communication technology, and I can find a hysterical article bemoaning the demise of all future relationships.”

Apps like Tinder connect people who otherwise might not have met.⁴ And they're becoming more efficient at it all the time.⁵ Apps curate our choices,⁶ make it easier to ask out a stranger,⁷ and take a lot of the risk (and cold sweats) out of first dates.⁸ When it comes down to it, though, online dating operates by the same social rules as dating in real life—and suffers from the same human flaws.⁹ But data shows it works.¹⁰

As more matchmaking apps flood the market, entrepreneurs will experiment with new algorithms and features. Some will flop.¹¹ But the ones that succeed will help us forge connections in ways we've never imagined.¹²

by
**MATT GILES
+ BREANNA
DRAHLER**

Eric Klinenberg,
sociologist at New
York University and
co-author of *Modern
Romance* with
Aziz Ansari

31

Percentage of
U.S. singles who
met a recent
first date online,
as compared
with 6 percent in
a bar or club,
according to
Match.com's
2014 Singles in
America survey

kind. But it has also brought more ideas to people's notice, so it kind of balances out."

⁷ "The world in general is not amenable to strangers meeting; that's why there are bars. Online dating is the newest venue created to meet people."

⁸ "You can online date from the privacy of your home. It's safer in some ways because you're not three beers in when you're meeting someone."

⁹ "People are not good predictors of what they actually want. People have beliefs or biases that they're not aware of, that they don't want to own up to."

¹⁰ "Already a third of all marriages start online. And marriages take time. So imagine what that rate will be in three years."

¹¹ "Dating will be photo-based until someone solves how to do video. But that content is way harder to moderate; Chatroulette

is the prime example. You can't let users upload videos of anything they want and hope for the best, because your site will fail."

¹² "Future apps will allow you to make an online connection to someone you're next to in real life but don't have a way to contact. Geospatial will be the main thing. Version 3.0? I think it's going to be teleportation. I'm kidding. Oh man, if I knew the answer to that question, I'd quit my job and move to Silicon Valley."

to see expanded answers and outtakes from the photo shoot.

Decoded



First found in boxers and called "punch-drunk syndrome," CTE now shows up in the brains of former NFL players too.

Tackling Brain Trauma Head-On

by JOE DeLESSIO

Legendary NFL linebacker Junior Seau committed suicide in 2012, less than three years after his final game. An autopsy overseen by the National Institutes of Health revealed that he'd had chronic traumatic encephalopathy, or CTE—a degenerative brain disease that can result from hits to the head and might cause depression, aggression, memory loss, and dementia. High-profile cases like Seau's

have raised public awareness of CTE in the NFL in recent years. And rather than a rarity, researchers are concerned the disease might be more widespread than previously believed.

"There's something about repetitive hits to the head that turns on this disease."

—ROBERT STERN, DIRECTOR OF CLINICAL RESEARCH AT THE CTE CENTER AT BOSTON UNIVERSITY

Boston University's CTE Center has been analyzing the brains of deceased athletes and veterans since 2008; the condition has shown up in 175 of the 247 brains studied. Among deceased NFL players, it's 88 of 92.

Currently, the disease can't be treated. In fact, doctors can't even diagnose it when a person is alive. CTE can be found only during autopsies. But that might be about to change.

"There's tremendous optimism that we can develop a way to identify this in living individuals," says Ann McKee, director of neuropathology at the CTE Center at Boston University. Some scientists are trying to find a CTE signature in blood, saliva, or spinal fluid. Others aim to track down a misfolded protein called tau, which is known to aggregate in the brains of people with CTE. By developing a radiotracer than adheres to this abnormal tau (and only this tau), researchers hope to be able to spot it in PET scans.

A team of researchers from Boston University and two local hospitals is testing a tracer called T807 in clinical trials backed, in part, by the Department of Defense. They're injecting it into former NFL players and expect results on its effectiveness within the next few years. This past April, a UCLA team developed a technique using a tracer called FDDNP, though some researchers question whether it attaches exclusively to tau.

"There's been incredible growth in tau neuroimaging, just in the past three years," says Robert Stern, director of clinical research at Boston University's CTE Center.

"Millions and millions of dollars are being poured into this gigantic area of research." At this pace, scientists—including Stern and McKee—anticipate they could

be diagnosing the condition in living brains within a decade. Researchers can then work on treatments to reduce tau or its effects on the central nervous system, putting the brakes on the disease before it's too late.

Insane Study

Faster Food, Fewer Neurons

Need another reason to avoid fast food? Australian scientists found that people with a diet of processed foods and sugary drinks tend to have a smaller hippocampus—a brain region involved in learning, memory, and mood. "Unhealthy diets can create an environment that is toxic to the brain," says neuroscientist Nicolas Cherbuin. So you might want to lay off the Big Macs.

by
STEPH YIN

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Concepts & Prototypes

The Warship to End All Battles

by
ADAM PIORE

In 1906, the Royal Navy rendered all other battleships obsolete when it unveiled the HMS *Dreadnought*: a steam-powered fighting vessel with 12-inch guns and cement-reinforced armor. This past summer, British naval engineers revealed a vision of its successor, the *Dreadnought 2050*.

The stealthy, semisubmersible ship is designed to move agilely around a battle zone and remain flexible in any type of mission, says Mark Steel, a manager of the Combat Systems Team at BMT Defence Services, a naval design firm involved in the project.

The battleship could function with a crew as small as 50, as opposed to the usual 200. It would serve as a mobile command center, unleashing and directing armies of drones, missiles, and rovers. "Robotics allows us to operate the ship at range to keep people out of harm's way," Steel says.

1. MOON POOL

The moon pool—a floodable dock area at the ship's stern—would allow for the rapid deployment of unmanned underwater rovers or Royal Marine divers.



2. DRONE LAUNCHER

An extendable flight deck and hangar would enable the launch of remotely piloted drones, many of which could be 3-D-printed on board.



3. TETHERED QUAD-COPTER

Above the ship, a hovering quad-copter would provide 360-degree visibility. Its sensors could capture emissions at frequencies across the electromagnetic spectrum to detect

enemy ships. A cryogenically cooled tether made of carbon nanotubes would transmit energy from the ship to keep it flying. Also, the quad-copter could be equipped with lasers that could take out close-range threats, such as enemy missiles, craft, or pirates that have slipped past the ship's other defenses.

4. SEE-THROUGH STRENGTH

The ship's hulls would be made of ultra-strong acrylic coated in graphene (the material's hydrophobic properties cut down on drag). "Smart

windows" would change to translucent when a certain amount of voltage is applied, allowing unobstructed views of close-in operations.



In addition to the main hull, two outrigger hulls, or armas, would contain tubes for launching torpedoes.

5. STEALTH PROPULSION

To propel the ship, a fusion reactor (or, if that fails to materialize, highly efficient turbines) would drive silent electric motors. *Dreadnought* would also be the first surface fighting ship able to use ballast to lower parts of the ship below water, making it harder to detect with radar or infrared.

6. HOLO-OP ROOM

Inside the *Dreadnought's* control room, commanders could zoom in and out of battles using a holographic command table. This would offer a 3-D view of a battle in real time from any vantage point—in the air, on the ocean's surface, on land, or even underwater.

7. FIREPOWER TRIFECTA

First, the ship would be armed with hypersonic missiles capable of knocking out would-be attackers. Second, it would have super-cavitating torpedoes. These rocket-propelled weapons move so

fast, they vaporize the water around them to create a nearly frictionless air bubble. These could pursue enemy ships at speeds of 300-plus knots. Third, an electromagnetic railgun could fire projectiles hundreds of miles, comparable to today's long-range missiles.



Want to Prevent Another Ferguson? Use data, not force.

The deaths of Oscar Grant III, Eric Garner, Michael Brown, and scores of others at the hands of law enforcement over the past few years have shaken Americans' faith in their police departments. According to a 2014 Gallup poll, 44 percent of Americans said they have only some or very little confidence in the police. It does not bode well for democracy when a population so widely distrusts those sworn to serve and protect it.

So how did we get here and what can we do about it? Part of the answer has to do with law enforcement methods. For decades, police forces in many cities have relied on policies such as broken windows and stop-and-frisk. The idea was to crack down on minor offenses in order to discourage more serious crimes. But the decisions of where and when to implement these methods were based on an officer's

by
MATT GILES

observations and hunches as much as (or some would argue more than) on hard data about previous crimes committed. Such policies—once highly praised—are

now falling out of favor. Critics maintain that they drive officers to unfairly (and in most cases unwittingly) target minorities. Those biases, real and perceived, are the fulcrum of our national distrust.

But a new model is emerging. Over the past two decades, the National Institute of Justice has awarded \$24 million to organizations to map crime and develop so-called predictive policing: using data to determine where future crimes might occur and patrolling those areas proactively.

One forerunner in this field is Hitachi Data Systems, which has developed a software system called Predictive Crime Analytics. In addition to crime and arrest reports, PCA can continuously comb license-plate scans, weather and traffic

reports, security camera footage, and Twitter. It layers those data sets onto a digital map so officers can monitor patterns in real time. Instead of following a hunch on who looks suspicious, officers can rely on algorithms to anticipate and act on trends from the data. "PCA is anonymous," says Mark Jules, who led the system's development at Hitachi. "It shows you an area. It does not tell you to look for a person."

In theory, predictive policing could add more analytical oversight to old-school police work. It could also allow law enforcement to monitor every part of a city in one fell swoop. But to realize those benefits, the data fed into the system needs to be neutral in the first place. "It is tempting to think that you put data into a system and out comes an unbiased analysis on other end," says Rachel Levinson-Waldman, senior counsel at New York University's Brennan Center for Justice. "But the data is coming from somewhere, and there is a concern these algorithmic models will re-create biased or racially disparate patterns."

That's a valid concern, but the only way to know if data can enforce justice without reinforcing bias is to try. So try we must.

Next year, a beta version of PCA will be launched in six yet-to-be-determined cities. (Washington D.C. is rumored to be one.) PCA can't ensure that mistakes won't still happen, but to those citizens who feel under siege it should come as some relief that local police (hopefully) will no longer target them unjustly.

1,022

Number of Americans killed by law enforcement in 2015 (as of November 17) as tracked by *The Guardian*

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- Back or Knee Pain
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- Plantar Fasciitis
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ACCREDITED
BUSINESS

Virtual Reality Gets Real

by
ALLISON WILLIAMS

Time's up, real world. The long-predicted virtual-reality boom has finally arrived. Now anyone with some cardboard and a few lenses can turn an iPhone into a passable VR headset. By 2020, an estimated 38 million more-sophisticated devices—such as the Oculus Rift, which hits shelves this year—will be out in the wild. Over the past five decades, VR has advanced from its science-fiction roots to a future that, well, sounds pretty sci-fi too.

1962

1981

1995

2002

2006

2014

2020

2025

2030

2035

PAST

FUTURE

Morton Heilig—a cinematographer and the father of VR—patents the **Sensorama Simulator**. The refrigerator-size mini theater comes equipped with a vibrating seat and a wind machine to blast the viewer.

Tom Furness of the **U.S. Air Force** builds the first **immersive VR system**, a virtual cockpit with a wide field of view, to improve cockpit design.

Hollywood discovers VR. In *The Lawnmower Man*, VR causes a woman to go mad and a simpleton to become a genius. In *Virtuosity*, Denzel Washington enters VR to catch a killer. A critic blasts the latter as "numbingly frantic, in the manner of many videogames."

In the wake of 9/11, **VR-exposure therapy alleviates post-traumatic stress in civilians.** Another program, Virtual Iraq, later treats veterans experiencing PTSD by helping them revisit the trauma. It incorporates virtual rocket-propelled grenades and Black Hawk helicopters.

To distract burn victims from the excruciating pain of wound care, an immersive VR experience called **Snow World** helps patients focus instead on tossing virtual snowballs at mammoths and penguins.

Facebook buys Oculus Rift for \$2 billion. Mark Zuckerberg calls the display "one of the next most important computing platforms."

Magic Leap hopes to master "mixed reality." The VR startup's light-field displays could eventually enable viewers to interact with both the real world and a virtual object projected on it.

Streaming data could allow VR to render any physical location in real time. **Office spaces might all go virtual.**

Artificial intelligence and VR will dovetail, so **people could develop bonds with virtual humans.** At least that's the speculation of Hunter Hoffman, lead designer of Snow World: "The brain is pretty open to buying into that."

The haptics problem—recreating touch and pressure in VR—could be solved by stimulating nerves with electrodes, building on research into muscle-propelled force feedback at the Hasso Plattner Institute.



Hurricane in a Box—Just Add Water

STORM INTENSITY

The SUSTAIN lab re-creates historic storms and uses sensors to measure their wind velocity and wave dynamics. It can then alter them to model future storms and fine-tune forecasts and the resulting evacuation plans. “You’ll deal with a Category 4 storm a hell of a lot differently than you would a Category 1,” Haus says.

THE POWER OF SEA SPRAY

Sea spray might actually fuel a storm. When it explodes off the ocean’s surface, sea spray evaporates and transfers heat from the water to the atmosphere. This could affect wind friction on the surface of the water, which might change a storm’s intensity; scientists don’t know. “It’s difficult to measure spray, especially during a hurricane,” Haus says. Instead, SUSTAIN uses optical imaging to see how the spray interacts with wind gusts, which could improve hurricane-intensity forecasts.

The tank and air duct house 37 permanent sensors. Dozens more can be added to collect different data sets.

New York City is now expected to experience a flood on par with that of Hurricane Sandy every 130 years. That’s up from once every 3,000 years. To better understand and prepare for these kinds of cataclysmic storms, the University of Miami just opened a \$45 million lab, and at its heart sits a hurricane-simulator called SUSTAIN (SURge-STRUCTure-Atmosphere INTERaction—a tortured acronym, to be sure). The 75-foot, 30,000-gallon acrylic tank can be filled with salt or fresh water. Using a 1,700-horsepower fan and a 12-paddle wave generator, scientists can stir up an infinite variety of waves. “We can create the equivalent of a hurricane with winds over 200 miles per hour,” says oceanographer Brian Haus, SUSTAIN’s director. “That’s an off-the-charts Category 5.”

by
MATT GILES

COASTAL STRUCTURES

As sunset seekers buy up ever more high-risk coastal real estate, SUSTAIN plans to test how model houses and bridges will hold up in a storm. This will help civil engineers design structures that are both more resilient and economical. “Of course you can build a poured-concrete home with 4-foot-thick walls 20 feet in the air,” Haus says, “but who can afford that?”

OCEAN DYNAMICS

In the lab, researchers also plan to track how carbon dioxide moves from the ocean to the atmosphere in order to improve climate models. Soon, the SUSTAIN team will launch 1,000 drifters—floating devices that gather data on currents as well as turbulence and wind—in the Gulf of Mexico. The goal is to see how oil moves on ocean surfaces so scientists can better predict the effects of future spills and clean them up.

WANT TO SEE THE LAB IN ACTION? Go to popsci.com/stormlab.

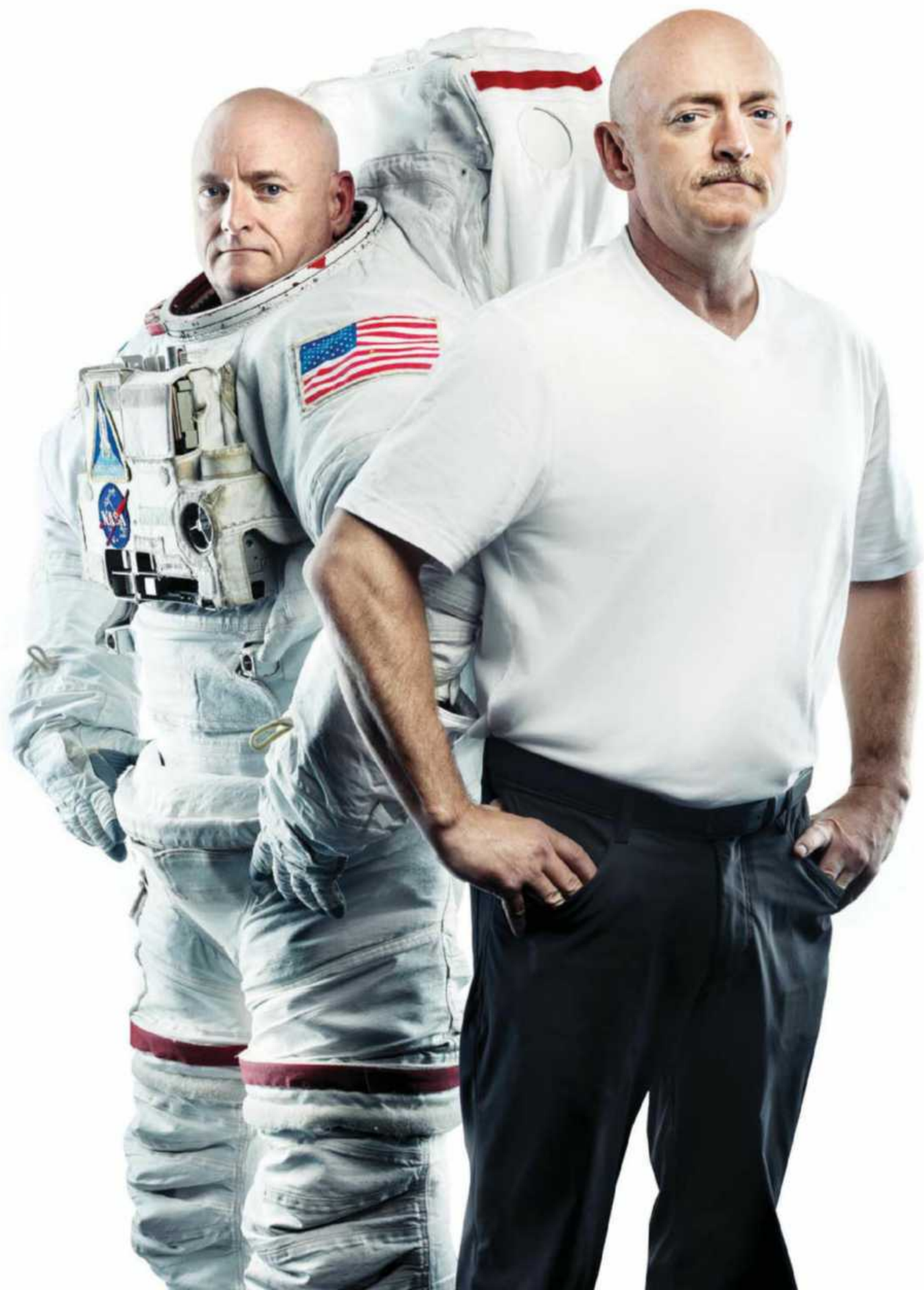
Big Ideas of the Year



Every year is a big one in science and technology. But 2016 will change the way we explore, connect, cure disease, and go to war. Here are the most influential ideas and extraordinary individuals poised to shape the year ahead.

Mark Kelly (foreground) and his twin brother, Scott, talk every day, despite their 249-vertical-mile distance.

TRUNK ARCHIVE





MARK KELLY & LIFIE IN SPACE

as told to
JENNIFER
BOGO

When astronaut Mark Kelly says, "I've spent a lot of time on Earth," it's relative. He's been to the International Space Station four times for short missions. His twin brother, Scott, is about to wrap up a full year in space, the longest stint of any U.S. astronaut. To understand how life in space affects humans, scientists are investigating how the twins' bodies now differ—information that might influence the future of long-term space exploration.

I ALWAYS THOUGHT scientists needed a large sample size. It turns out when you don't have that opportunity, a small sample can still lead to really useful science. In our case, it's just one sample: Scott as subject, me as control. I've spent only 50-something days in space. When Scott gets back in March, I think he will have spent something like 3 percent of his life there.

I have, on multiple occasions now, given massive amounts of blood. I've also given

saliva, stool, and urine samples—sometimes 24 hours' worth. And then, when I go to Houston every few months, I get MRIs of my brain and heart, and ultrasounds of my cardiovascular system and optic nerve. They send the ultrasound machine right into the goo on your eye. For some tests they put me in a contraption—a lower-body negative-pressure device—and have me take nitroglycerin. I don't even know what experiment it's for.

Scott's also drawing his own blood and sending it down to the ground for analysis. And there's an ultrasound machine aboard the space station. One of the researchers sent my brother an email that said they would have more scientific and medical information on Scott and me than on any other person, ever. The big question for us is, how much do we want to know? They're looking at not only our genetic profile but also

which genes have mutated. If a gene has turned on, then the risk for diseases like Alzheimer's and cancer really goes up.

I imagine that NASA is hoping to learn that space isn't a big deal, that it doesn't have that big of an impact on astronauts. That would be great. But I think the reality is that it does, and so we're going to have to learn how to mitigate those effects. Maybe we shield crew members from radiation. Or maybe we could figure out a way to repair our genes. Think about the implications for your average person on Earth.

I applaud the enthusiasm of people who would sign up for a one-way trip to Mars, but they wildly underestimate the issues involved, not only to their physical but also to their mental health. Imagine if you were plopped down in a Winnebago in Death Valley, left there for the rest of your life, and had to put on a suit to go outside? The novelty would wear off. But I do think the first person to walk on Mars is alive today.

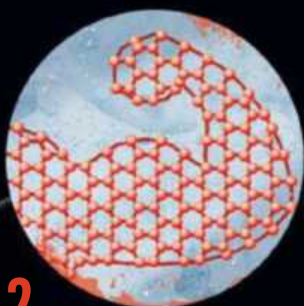


1. A NEW WEAPON TO FIGHT SUPERBUGS

IN 2015, scientists discovered the first new antibiotic in three decades. Called teixobactin, it works against several of the superbugs, such as MRSA, that today's drugs seem powerless to wipe out. That's a big win in an age of growing antibiotic resistance. But perhaps even more pivotal is the tool that made its discovery possible.

Antibiotics come from bacteria found in nature. Test more bacteria, and you can find more antibiotics. The challenge is this: 99 percent of the microbes on Earth can't be cultured in a dish. To work around this problem, researchers at Northwestern University invented the iChip, which can grow microbes in a sample of soil or water from their natural environments. When the bacteria release antibiotics, scientists can isolate them for testing.

The team has used the iChip to culture thousands of new bacteria, which have so far yielded 25 antibiotics. According to Novobiotic Pharmaceuticals, a company co-founded by one of the researchers, the first of those is roughly two years from clinical trials. "There's still a lot of work to be done," says Stuart Levy, director of the Center for Adaptation Genetics and Drug Resistance. "But because of this device, the door is open and a bright light is on." **ALEXANDRA OSSOLA**



2. THE RISE OF SUPER-MATERIALS

ENGINEERS are taking materials into a whole new dimension: the second dimension. By transforming 3-D clumps of atoms into 2-D sheets, researchers are finding amazing untapped potential in ordinary-seeming elements.

The 2-D revolution began more than a decade ago with the discovery of graphene, a mesh of carbon atoms linked together like the wires in a chain-link fence. It's transparent but more than 200 times stronger than steel, nearly impermeable, and an excellent conductor. Turning graphene into practical devices has been a challenge, but teams are now closing in on a few: ultra-high-density computer flash memory, a broadband radiation detector, and a tool for precision medical imaging.

Other 2-D materials might prove even more impressive. Scientists have begun creating analogous meshes of silicon (silicene), phosphorous (phosphorene), germanium (germanene), and tin (stanene). Silicon and phosphorus are particularly well-suited to making atomic-scale transistors that could lead to extremely fast, efficient, flexible electronics.

The goal for 2016 is to mix and stack flat materials to combine their best qualities. A team at Lawrence Berkeley National Lab has started building 2-D sheets that function as a laser, with applications that range from quantum computing to—ironically—3-D displays. **COREY S. POWELL**



3. LIGHTBULBS CAN MAKE US HEALTHY

THERE'S PERHAPS no more powerful force in nature than light. It influences everything from our cells to our mood and metabolism. Blue wavelengths cue the brain to produce cortisol to make us alert, while red wavelengths allow the production of melatonin to help us sleep—a cycle that once followed the sun and moon. The invention of the lightbulb (and smartphones) changed that. Engineers are now using lightbulbs to change it back.

"The science has led us to understand that the light we've been using for the past 100 years has caused damage to us," says Fred Maxik, founder of bulb-maker Lighting Science Group. When our circadian rhythms went rogue, it increased our risk of developing obesity, depression, and even cancer. That doesn't have to be the case, Maxik says: "We have the ability to create lights that have purposes other than just illuminating our world."

Such bulbs have started to reach sockets. Last year, the Renton School District in Washington became the first to install tunable LEDs. They can be adjusted from red wavelengths, to calm students after recess, to blue, to improve test-day concentration. The Seattle Mariners installed LEDs at Safeco Field that can make nighttime games seem more like day; the New York Yankees will follow suit in 2016.

This year, NASA also plans to change the bulbs on the International Space Station, where the sun sets every 90 minutes, and constant light makes astronauts chronic insomniacs. The new bulbs will subtly shift from blue wavelengths during the workday to red when the crew needs to rest. LEDs like Lighting Science's new Genesis Light, which hits shelves in January, will do the same thing for homes.

"We have been in this era of efficiency," says Michael Siminovitch, a University of California at Davis professor of lighting design. "Now what can we do with technology that actually does something for us?" **REBECCA BOYLE**



IMOGEN HEAP & HACKING THE MUSIC INDUSTRY



as told to
MATT GILES

The Grammy-winning musician Imogen Heap has long used technology to interact with fans. Now she wants to use it to radically change the music industry. Heap envisions a platform, called Mycelia, that will use blockchains—the system that underpins Bitcoin—to create a transparent, decentralized database of music. It will cut out middlemen and enable artists and followers to connect directly.

AS A MUSICIAN, I like to think the world revolves around me. For years I wondered why it took so long for money to filter back to me, or why I didn't know what the fine print of my record deals really said. For the first time in my career, I am on my own—I am not signed to any record label or represented by any management. Success has already opened a lot of doors for me, so I wanted to put myself in the position of being a brand-new

artist. I imagined, if I could design the music industry from scratch, knowing what I know, how would I do it?

I realized that the architecture of the industry is built on an old paper system and defunct technology. We spend billions on accounting systems that no longer work. It doesn't make any sense in this data-driven world, where we can access any type of information we want. There are now ways to connect data to payment instantly.

At the moment, Mycelia is just an idea; nothing has technically been built. But I think of it as a living organism—a system that breathes and responds to plays. The music would come from a portal, and listeners would get some kind of notification that it has been verified by the artists. Each artist would have a profile, and everything

connected to that song or album, like lyrics, photos, and who played which instruments, will act like a beacon of information: "Here I am! Come and get me!"

The system will be fair and transparent. Because the artists have complete control, we will split the money with exactly who should be paid. And because everything is connected through blockchains, the transfer of money will be instantaneous. We can also decide whether we want to release our music for free, or what the subscription base should be, or whether to agree to a per-play model. It is liberating.

My latest song, "Tiny Human," has been a test case, and to be honest, money is coming in slowly. I've got an account and various cryptocurrency wallets, but there aren't many adopters yet. What is really exciting, though, is the solidarity of building something with other musicians. The idea hit a nerve, and I feel a responsibility to capture this energy and turn it into something.



BETH STEVENS & THE BRAIN'S BEST-KEPT SECRET

A neuroscientist at Harvard Medical School, Beth Stevens knows how your brain is wired—quite literally. Because of her discovery that certain cells sculpt brain circuitry, making it more efficient, the MacArthur Foundation awarded her a 2015 “genius grant.” She suspects those cells, called microglia, have other secret abilities—and she plans to uncover them too.

as told to
MATT GILES

I’VE BEEN INTERESTED in glial cells—which make up more than half the cells of the brain—since I was a research assistant at the National Institutes of Health. Of the three types of glial cells, microglia are my favorite. There is so little known about them, which is crazy because they make up 10 percent of our brains.

For years, scientists essentially ignored microglia. One of the things they do is prune synapses. There are trillions of synapses in the brain, but initially you start with way more. Synapses that are firing a lot get strengthened, and those that are not firing very much get eliminated. Microglia are like the brain’s Pac Men—

regulated garbage collectors that eat synapses that no longer function.

We think certain disorders are the result of microglia pruning too much, or not enough. This has huge implications for diseases like autism, schizophrenia, and Alzheimer’s. If the microglia don’t prune properly, it can lead to faulty wiring.

I think pruning is just the tip of the iceberg. We recently learned that microglia enter the brain during embryonic development—so early that they have to be doing other things. I have a hypothesis that they form synapses, and could be involved in helping to regulate the growth and development of newborn neurons.

Because of the MacArthur, these cells now have a bit of limelight outside this field. Even my mom knows what microglia are now. The award also means the difference between pursuing conservative projects and projects that are still just ideas on a whiteboard. My lab plans to really dig in and test whether microglia play a key role in neurological diseases.

I don’t believe there is a magic bullet for anything these days, but if you can understand what regulates microglia, I think you can slow the onset or progression of these diseases. And if you can figure out how to manipulate microglia, you can develop a drug that could potentially treat them—which is a big deal.





4 KILLER ROBOTS ARE COMING

IN AUGUST, STEWART RUSSELL, a computer scientist at University of California at Berkeley, authored an open letter calling for the ban of “lethal autonomous weapons.” To those outside the military-industrial complex, this could seem a bit premature, sort of like calling for a ban on *Star Trek* phasers or the Death Star. Reality says otherwise.

Humans have a venerable tradition of automating warfare. Land mines are a kind of robot, though a very dumb one. Heat-seeking missiles are smarter, albeit not by a lot. “There’s a continuum,” Russell says, and we’re further along it than we realize. “If you wanted to produce something very effective, pretty reliable, and if it became a military priority—in 18 months you could mass-produce some kind of intelligent weapon.” Indeed autonomous killing machines already exist: The Super aEgis II, a South Korean-made weapons platform, can recognize humans and target them. (It will request permission from a living operator before making a shot with its .50 caliber gun, but that’s more a courtesy than a requirement.)

Russell writes that “autonomous weapons will become the Kalashnikovs of tomorrow”—cheap and abundant. And that shifts the rules of war. “AI weapons could change the scale in which small groups of people can affect the rest of the world,” he says. “They can do the damage of nuclear weapons with less money and infrastructure.”

Proponents of AI weapons point to some upsides: Robots going to war would mean fewer human casualties. But to the 20,000 people (the majority of whom are scientists) who signed the letter, the costs far outweigh the benefits. Later this year, Russell and others will push for legislative stopgaps and a change in international law, similar to those that prohibit biological weapons. Meetings are set at the United Nations and the World Economic Forum. Once killer AI is here, there’s no going back. RYAN BRADLEY

BIG IDEAS



5. CRISPR REMAKES THE WORLD

THE GENE-EDITING technique called CRISPR has the much-hyped potential to revolutionize medicine, deliver designer babies, and end global hunger. Developed from a mechanism found in bacteria, CRISPR allows scientists to cut-and-paste DNA with unprecedented precision. The researchers behind its discovery are favorites to win Nobel prizes in 2016.

In the three years since CRISPR was introduced, it has been adopted by thousands of scientists worldwide. Already, they’ve used the technique to create hypermuscular beagles and pigs that can grow human organs for transplant. Innovations that used to take many years to realize can now be made in mere months. “The technology is pretty darn fast,” said Dan Voytas, a genetic engineer who has edited wheat to reduce gluten sensitivity. “In a year we can generate a plant from just an idea for one.”

As a result, CRISPR-based startups are busily raising hundreds of millions of dollars. Patent applications that mention CRISPR have soared, from 43 in 2013 to 292 last year. And while the first products—things like hornless dairy cows and hypoallergenic peanuts—are still a few years from market, this will be the year gene editing transforms life as we know it. MEGAN MOLTENI



6. MARIJUANA REACHES NEW HIGHS

IT’S NOW EASIER to buy marijuana in the U.S. for personal consumption than it is for scientists to procure it for research: 23 states and D.C. have legalized it (at least as medicine), and several others may have it on the ballot in 2016. Researchers hope the barriers to studying the plant will likewise crumble so they can finally probe its full therapeutic potential.

Scientists have long known that marijuana can treat nausea and pain. But they only recently figured out why: Chemicals in marijuana called cannabinoids can activate receptors on brain cells, changing the messages they send to one another. While THC is the best-known cannabinoid, researchers suspect others might be useful in treating the symptoms of diseases such as cancer, fibromyalgia, epilepsy, and autism.

So far, even in states where medical marijuana is legal, scientists have had to wait months or years for approvals from the Drug Enforcement Administration, Food and Drug Administration, and National Institute on Drug Abuse. In June, the White House took one step out of the complex process: They no longer need permission from the Public Health Service too. In November, Senator Bernie Sanders introduced a bill that would remove marijuana from the list of substances regulated by the DEA—a move that would take it out of the company of heroin and make it much easier for a lab to buy. ALEXANDRA OSSOLA



7. YEAR OF THE ZETTABYTE

BY THE END of 2016, Cisco estimates that Internet traffic will bypass 1 zettabyte. For those who think of storage in the relatable terms of a smartphone, a zettabyte is 1,000 exabytes, which translates into 1 trillion gigabytes—or roughly 300 trillion photos of your baby and dog.

The profusion of data from phones, wearables, and the Internet of Things affords us new insights. But it also opens the door to hacking. “We never thought about the implications of all this additional data,” says Samy Kamkar, an independent security researcher and hacker. “We’ve all become targets.” According to IDC, 90 percent of IT networks will have experienced a security breach by the end of this year.

But as hacking grows, so too does cybersecurity. The research firm MarketsandMarkets estimates the email-encryption market will increase 23 percent annually until 2020. This past year, Gmail began developing warnings for messages that come through a non-encrypted connection, Netflix decided to encrypt all its data, and the Electronic Frontier Foundation launched the Let’s Encrypt program, to transition the Web to the more-secure HTTPS protocol. While the extra protection won’t necessarily make us impervious to hacks, says Kamkar, “when it does happen, it won’t undermine your life like before.” **MATT GILES**



8. POLLUTION CAN BE INHERITED

MOST PEOPLE KNOW that an individual’s environment has clear health effects. Drink water laced with heavy metals, and you’re likely to get sick. What’s now becoming apparent is that those impacts could last for generations.

A person’s genome controls development, function, and reproduction. In other words, just about everything. But the genome doesn’t act unchecked. It is subject to the epigenome—chemical compounds that help determine how and when genes express. In 2014, a group at the University of British Columbia reported that just two hours of exposure to diesel fumes in a closed space could affect about 400 genes by altering the epigenome. And last year, researchers in North America and Europe published a number of papers that indicated such changes could be inherited.

“The field is exploding right now,” says Carrie Breton, who studies the effects of prenatal air-pollution exposure at the University of Southern California. Energized by new findings and the completion in February of the first full map of the human epigenome—a 10-year, \$240 million initiative—scientists are racing to understand how epigenetic changes can alter the likelihood of cancer, obesity, diabetes, and other diseases. “Can we sequence the epigenome to look for environmental effects?” Breton asks. “Technologically, this is the next logical step.” **CLAY RISEN**



A SECOND ACT FOR SPACE EXPLORATION

WHEN NASA’S *New Horizons* probe skimmed past Pluto this past July—50 years to the day after *Mariner 4* first snapped photos of Mars—humans completed reconnaissance of the solar system. We had sent probes past all nine planets (eight by today’s measure) and landed on every major type of object in the solar system: rocky planets, rocky moons, icy moons, asteroids, and comets. We have left behind the era of first looks, and entered the age of true understanding.

In that spirit, the next generation of planetary missions will look past surface appearances. NASA’s *InSight* probe, launching in March, will establish a seismic station on the Red Planet; it will sense marsquakes and use them to map the planet’s interior. A complementary European-Russian probe called *ExoMars 2016*, lifting off almost simultaneously, will use a chemical sniffer to ferret out atmospheric methane from possible Martian microbes. Then in September, *OSIRIS-REx* will head to Bennu, the kind of carbon-rich asteroid that may have seeded ancient life on Earth, to collect samples and bring them home for analysis.

Equally notable is a move to open the solar system to all. The *InSight* probe will bring two miniature satellites, or CubeSats, that will go into orbit to create a dedicated Mars communications network. Student-built CubeSats are already widely deployed around Earth; if *InSight*’s work, expect the DIY movement to spread to other planets. NASA’s *Juno* probe, which reaches Jupiter in July, has an even more populist mission. It carries a camera designed solely for students and citizen scientists—the first time an entire planet has been turned over to the public. In the words of NASA’s John Grunsfeld: “Five hundred years from now, we will look back on this as the golden age of exploration.” **COREY S. POWELL**





10. INTERNET FOR EVERYONE

BY THE END of 2016, Facebook plans to launch its own satellite. The *AMOS-6*—built and deployed with French firm Eutelsat—will provide Internet access to millions in sub-Saharan Africa, where in several countries fewer than 2 percent of the population is online. Also this year, Google will begin testing balloon-powered Internet service in Indonesia, whose more than 17,000 islands stand in the way of nationwide infrastructure.

"The easy-to-reach populations have already been reached," says Joshua Meltzer, a senior fellow at the Brookings Institution who has studied the Internet's impact on poor countries. Smartphones and Internet cafes have proliferated in places with cell towers and stable grids. "But there are still 4 billion people who don't have Internet access," Meltzer says. "And they are increasingly in the developing world."

The benefits of access go beyond posting cat pics. Individuals can transfer funds without a bank account, and local businesses can plug into the global economy. For that reason, the State Department's Global Connect initiative, which kicks off this year, hopes to exert diplomatic pressure to bring the Internet to 1.5 billion people by 2020. As Mark Zuckerberg told the United Nations this fall, "Internet access needs to be treated as an important enabler of human rights." ERIK SOFGE

JAMES CRAWFORD & A NEW WAY TO SEE THE WORLD

After stints running Google Books and heading up the team tasked with giving Mars rovers autonomy, James Crawford launched Orbital Insight—a startup that applies artificial intelligence and data analysis to satellite imagery.

as told to
TOM FOSTER

MOST PEOPLE KNOW that humans can't see really small things. That's why we invented the microscope. On the flip side, humans also struggle to see really big things. If you want to view the whole Earth, for example, you have to look from space and you lose a lot of detail. Every pixel your eye sees is 10,000 square miles. Using artificial intelligence and cloud computing, we can simultaneously see the whole Earth and see the detail. We can look at trillions of features within millions of satellite images all at once. We call this a macroscope.

Our machine-vision algorithms allow a computer to identify an object as a car or a truck, a house or a building, and so on. Once we have that data, we try to pull meaning from it, whether that's a prediction of crop yields or how much oil will soon enter the marketplace. The question then becomes, what does this enable us to do that was previously impossible?

One cool example is a project we're doing with the World Resources Institute. WRI already uses satellite imagery to spot deforestation. But what you want to know is which forest will be cut down next, because then you can do something about it. We will be able to detect the road building, the initial thinning, and the other preparations that go on in advance of major deforestation events.

Governments could also benefit from our technology. There's evidence, for instance, that the Arab Spring was partially triggered by a doubling in the price of wheat in the Middle East, due to droughts in Ukraine and other countries that weren't being well-tracked. Imagine if we could track food security in real time.

I just think back to the microscope. It led to a revolution in biology and changed our understanding of the world. The macroscope, we believe, could lead to a revolution of its own.



THE LAST FIGHTER PILOT

THE NEW F-35 FIGHTER JET IS SO SOPHISTICATED, SO AUTOMATED, SO CONNECTED, IT'S FUELING A DEBATE: DO PILOTS STILL NEED TO FLY?

BY KEVIN GRAY

PHOTOGRAPHY BY SPENCER LOWELL

ON

A DUSTY TARMAC, about 20 miles from downtown Phoenix, Capt. Joseph Stenger stands in 109-degree heat, barely sweating. A 32-year-old fighter pilot with the slicked-back hair, steady eyes, and ropey forearms you see on movie posters, he is admiring an equally impressive piece of flying machinery: the F-35 Lightning II fighter. In his green flight suit, and standing a little over 6 feet tall, Stenger is nearly face to snout with this menacing jet. It's his job to figure out what it can do in combat, and to teach that to hundreds of other fighter pilots.

The F-35 started arriving here at Luke Air Force Base this past winter. It is the most sophisticated fighter ever built. It is stealth, so it can appear the size of a golf ball to enemy radar, if it's detected at all. It can also jam enemy radar—or make it seem there are 100 golfball-size targets in the sky. It can travel at Mach 1.6. It carries a 25 mm cannon, air-to-air missiles, two 2,000-pound guided bombs, and four external laser-guided bombs. But what truly sets it apart is its brain, 8 million lines of software code—more than any fighter in history—fusing navigation, communication, and targeting systems.

Stenger explains it like this: In older jets, he has to manually operate things like radar (pointing it at the ground to search for missiles shot at him, or at the sky, to look for enemy planes). He has to monitor a high-speed data link for plane-to-plane communications and texts from ground troops. He or his back-seat weapons guy must pick through data before locking on a target and firing. “You can imagine that's pretty time consuming and requires a lot of cognitive processing,” Stenger says.

The single-seat F-35 does much of this for him, by fusing and automating dozens of sensors. So, for instance, if his heat sensor picks up an enemy missile headed his way, a chime will sound, “like a doorbell” he says, and a computer voice will say, “Missile left, nine o'clock.” When Stenger looks there, a green circle pops up on his helmet's face shield, pinpointing the missile's site, along with its speed and time to impact. Just by looking at the circle Stenger can aim his weapon and fire at the enemy, then outrun the missile. Six external cameras also capture a 360-degree view outside the jet and feed it to his face shield. If Stenger looks down he can see through the cockpit floor to the ground.

Lockheed Martin, the defense contractor that makes the F-35, will deliver thousands of these jets over the next few decades to the U.S. Navy, Marines, and Air Force. The USAF will take 1,763, and Stenger will help train the aspiring F-35 pilots set to come through Luke's sand-colored gates. With more than 200 flight hours in the F-35 so far, he knows it as well as any Air Force pilot here. When he's not on the flight line, he spends days in classified briefing

**“IF ANOTHER
MANNED FIGHTER
COMES UP, GREAT.
IF NOT, THAT STINKS
FOR THE NEXT
GENERATION.”**

**—AIR FORCE CAPTAIN
JOSEPH STENGER**

rooms, reading tactical manuals on the F-35's capabilities. He can tick off the jet's attributes like a new crush. Stenger and most others in the military see the plane as the key to America's continued air superiority, and yet it could also spell the beginning of the end for an iconic American profession. The F-35 is so high-tech, so automated, so smart, so connected, that in May, the secretary of the Navy, Ray Mabus, declared: The F-35 “should be, and almost certainly will be, the last manned strike fighter aircraft the Department of the Navy will ever buy or fly.”

To Mabus and others, the job of a fighter pilot has changed over the years. No longer do pilots sneak up on each other's tails, train their crosshairs, and fire. They glean information from screens that look like iPads or from helmet displays. Electronic sensors, networked warfare, and air-to-air radar-guided missiles can take down enemy fighters from 100 miles away. Most of the time, pilots in a conflict never see one another at all. If that's the case, many argue, why not have pilots on the ground—scanning the same screens and pushing the same buttons—out of harm's way?

Stenger has considered this question before. As a pilot in Afghanistan, he flew more than 330 combat hours, doing things like blowing up Taliban fighters and safe houses, taking out missiles launchers, and providing cover for coalition forces. And yet, in his nine years in the Air Force, he's never been in a dogfight or even encountered an enemy fighter—or any sort of enemy aircraft. When faced with the argument for unmanned fighter jets, he takes a philosophical line. “I wouldn't offer up a conjecture because I'm a captain, and my job is to fly the F-35,” he says. “And that's what I'm going to do. If another manned fighter comes up, great. If not, well that kind of stinks for the next generation because they'll never get to know what being a fighter pilot is like.”



LUKE IS TYPICALLY a busy Air Force base. Every 15 minutes, the desert air rumbles with the sound of jets taking off and landing. For the past 32 years, it has served as a major training base for the F-16 Fighting Falcons that sit in endless rows beneath sun canopies on the flight line. Those planes will be phased out as the F-35s arrive and squeeze them for space.

During flight training, Stenger's students learn many skills, and dogfighting is still among them. With 1.7 million acres of Sonoran Desert and 57,000 cubic miles of airspace at his disposal, Stenger can orchestrate the kind of tactical dogfight scenarios seen in *Top Gun*. “We can set up 100 miles apart for air-to-air combat training,” says Stenger, seated in a bare second-floor office, which he moved into in July. In training, Stenger would pit two of his F-35 students against four F-16s fighter pilots. (This is the same class of fighter jet that Russia and China possess, and the type that could face off against the F-35.) “You employ the tactics you were taught, and you will kill them before they ever see you,” Stenger says, “well beyond visual range.”



The F-35 Lightning II uses
8 million lines of software
code and can reach Mach 1.6.



That phrase is crucial to the argument for unmanned fighter jets. Nearly every air-to-air engagement on the planet has been well beyond visual range since the early 1990s. That's around the time modern militaries began relying on networked warfare: A system that combines GPS satellite locators, infrared radar, secure data links for ground and air-to-air communication, surveillance aircraft like Boeing's E-3 Sentry, and, of course, radar-guided air-to-air missiles.

As networked warfare has risen, incidents of aerial combat have decreased. Since 1990, only 54 fighter jets have been shot down globally, says John Stillion, a senior fellow at the Center for Strategic and Budgetary Assessments, and a former Air Force officer, who put together a database on all confirmed aerial victories between 1965 to 2013.

Of course, geopolitics can partially explain that trend. Few nation states with fighter jets have been warring with each other in that period. But Stillion argues that technology is driving change as well. The increase in sensor-driven flying and beyond-visual-range shooting, he says, has rendered a jet's traditional strengths—things like high speeds, acceleration, and maneuverability—less important than they once were. What matters most now, he argues in a recent paper, "Trends in Air-to-Air Combat: Implications for

Future Air Superiority," are sensors, powerful and long-range weapons, aircraft flight range, and network connectivity.

"Those are things normally associated with long-range bombers," Stillion says. "So maybe our future fighter jets resemble unmanned long-range strike platforms."

It's an interesting position, and one that makes both technical and fiscal sense. Drones can pretty much do—and in some ways do better—everything a manned fighter jet can. They can stay aloft 24 hours at a time, while manned fighters are limited to the amount of time a pilot can stay in a cramped cockpit seat, several hours at best. In addition, drones don't need to be trained and retrained, as pilots do. And ending that practice could save a lot of money.

The cost of training can be staggering: The Air Force spends \$14,183 an hour to fly a single F-35A, according to the 2015 Department of Defense Budget. That's just in peacetime training. Budgeting 13 hours of crew time per month, that equals \$2.2 million a year, for one crew's training. When its F-35 training program is fully running in a few years, Luke will have 144 of those planes. Each squad on the base will be made up of 24 aircraft with several hundred support personnel. When you do the math, people are expensive and impractical.



THOUGH MANY AGREE that the role of fighter jets, and therein fighter pilots, will change in the future, how that will play out is up for debate. Stillion argues that the next-generation fighter jet should more closely resemble long-range strike bombers. Those planes are bigger than fighters, by far. They could carry a crew—one even big enough to swap out shifts—but they wouldn't have fighter pilots, per se. Instead, the bomber would be equipped with long-range missiles and a complement of four drones, each of which would have its own advanced radar and medium-range missiles.

In a future dogfight against nations like China or Russia, Stillion envisions those drones flying in a picket line deep into enemy territory, and acting as lookouts. The bomber would follow about 100 miles behind them. The crew would control the drones and use them to double the bomber's sensor-detection range. As Stillion depicts it, in a duel against eight fighter aircraft. At that point, the bomber team would fire long range missiles (good for about 250 miles), taking out up to six enemy jets at once.

Stillion is not alone in reimagining aerial combat. Lockheed Martin's experimental Skunk Works site in California has dozens of technicians combining unmanned systems with artificial intelligence. Its secret Minion project is developing a reconnaissance drone,

like Stillion's advance drones, that would also jam enemy radar, drop GPS-guided bombs, and shoot a high-powered microwave to disable electronics. "You could project forward to where there is a time when you can replace human cognitive capability with artificial intelligence," says Bob Ruskowski, director of advanced air dominance and unmanned systems at Skunk Works. But he also believes that there will always be a need for "a mixture of manned and unmanned working together."

Northrup Grumman's engineers are focused on the problem too. Its experimental X-47B unmanned combat jet has already made successful takeoffs and landings from an aircraft carrier (as well as made midair refuelings). The company believes a dogfighting drone is just years away.

What might slow progress are the ethical questions that arise when speaking about drone fighter jets. "Sometimes war is about breaking things, and sometimes it really is about killing people," says Heather Penney, an Air National Guard F-16 fighter pilot who deployed twice to Iraq. "Even with remotely piloted aircraft, there are still humans in the loop. Regardless of how good Siri might become on your phone, I don't think we as a society will ever get to the point where we trust weapons platforms to make autonomous decisions about life and death."

"WE WILL NEVER TRUST A WEAPONS PLATFORM TO MAKE LIFE AND DEATH DECISIONS."

—HEATHER PENNEY, AIR NATIONAL GUARD

Penney knows that work well. On the morning of September 11, 2001, as a rookie in the D.C. Air National Guard, and its first female fighter pilot, she found herself at Andrews Air Force Base taking off in an F-16. Her orders that day: Bring down United Airlines Flight 93, packed with passengers—and hijackers—headed for the nation's capital. She had no ammunition. Rather, she was tasked with a suicide mission: Ram the plane if need be. The passengers ended up taking down the flight themselves.

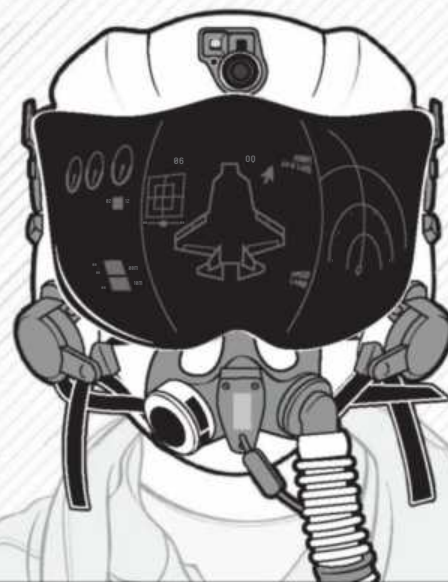
Penney, who works as director of USAF Air Superiority Systems at Lockheed, personally believes Stillion's concept makes a lot of sense. "But there are a lot of technological what-ifs that go along with it," she says. Among the biggest is the development of directed-energy weapons—lasers that will travel at the speed of light to take out aircraft and destroy network data links and communications. Every major nation—the U.S., China, Russia, most of the European countries—are pursuing them.

So if most of your air force is made of drones, and they rely on data links, and if the enemy can fry those links with an electric pulse, then your drone says, "I'm not talking to my pilot anymore; I'm going to fly home because that's what I'm programmed to do," Penney says. "Then the bad guy doesn't even need to shoot it down. The effect is the same. They've won the air space."

INSIDE THE F-35 HELMET

THE GEN III HELMET, BY CONTRACTOR ROCKWELL COLLINS, OFFERS SEVERAL NEW FEATURES.

- **Six external cameras feed video to the face shield, allowing pilots to see through the jet.**
- **A cueing system lets pilots aim weapons with their eyes.**
- **Built-in night vision allows for seeing in the dark**
- **A missile-warning system scans ground and air, alerting pilots to threats.**



Actual pilots, on the other hand, will work toward a mission objective even as the battle space degrades, Penney says. “They can sit gracefully operating, with manner and intent, and to the best of their ability.”

Penney also believes that only humans, not drones, can best figure out how to get in the enemy’s head and mess with it in a way that cripples him. “Your job is to create confusion in the enemy,” Penney says, “get in his line so you are making better decisions faster than he is, causing him to make mistake after mistake.” For that, she says, nothing can touch human cognition. So far.



FOLLOWING MY TOUR with Stenger, just as the Arizona sun is starting to bake Luke’s miles of tarmac, I head over to a freshly paved stretch of road in a far corner of the base. Things are quiet. There’s a rare three-day break in the flight schedule and the crews are taking advantage of the downtime. Despite the midday heat, teams of airmen play volleyball in a sand pit. Others sit on picnic tables, in the shade of pine trees, drinking Cokes and watching the games. The scene is so straight out of *Top Gun* that it conjures a Kenny Loggins backing track (though the heavysset airmen have none of the moves of Maverick and Iceman).

Nearby stands a two-story stucco building with a soaring atrium and a pitched roof that resemble jet wings. Recently constructed, it looks like a Southwestern high school, but it is a \$47 million training center. Inside it smells like new carpet and holds some 18 classrooms, a 240-seat auditorium, a vast expanse of as-yet-to-be-used cubicles, and, tucked behind heavily guarded double security doors, space for 12 brand-new, state-of-the-art, F-35 flight simulators that cost \$23 million apiece.

Lt. Colonel Rhett Hierlmeier heads up the center’s operations. The 38-year-old pilot used to fly F-15C Eagles out of Okinawa, mostly around the Pacific and Guam and Japan, and later F-22s. Both planes are air-to-air fighters. “So over the past 10 years, there’s really not been much for us to do,” he says, sitting in a sparse second-floor office, overlooking dozens of empty cubicles. “The deployments were really about presence, show of force.” He notes that the last time a U.S. Air Force fighter pilot shot down an enemy plane was in the late ’90s, during the Balkan Wars. “With Iraq, those guys ended up burying their jets because of our superior presence,” he says.

A former Air Force Academy instructor, Hierlmeier flew the F-35 for the first time three weeks earlier. His job here is to train up an instructor cadre who can then train hundreds of U.S. pilots, as well as pilots from eight coalition countries that have signed on to the buy the F-35. They include Australia, Norway, Canada, Turkey, the Netherlands, and Denmark. The current class is small, including four Americans, three Norwegians, and one Italian, but it will grow to as many as 300 pilots each year.



Air Force Capt. Joseph Stenger has 200-plus hours flying the F-35.

Hierlmeier leads me through two locked doors and into a vertiginous hall that looks like something out of a Dr. Seuss book: Every 15 feet or so, asymmetrical arches painted in disorienting reds and gray, recede down the hall, flanked by blue police strobes. Hierlmeier is not sure why, but they seem meant to confuse intruders. From hidden speakers, a Thin Lizzy song overpowers our discussion: *The drinks will flow and the blood will spill/and if the boys want to fight, you better let them.* When I ask if it’s to amp up student pilots, Hierlmeier, who is serious, says: “No. There are a lot of classified conversations taking place behind these walls. It’s meant to cover them up.”



**"I'M HOPING WE'LL
SEE A DAY WHEN
MAN IS NOT IN THE
MACHINE, BUT HE
IS IN THE LOOP."**

**-AIR FORCE LT. COLONEL
RHETT HIERLMEIER**

helmets, made by defense contractor Rockwell Collins, are custom-built for each pilot and cost upwards of \$400,000 apiece. "It's like wearing a laptop on your head," Hierlmeier says of their computing power.

The sims are the most advanced virtual-reality experience on the planet. A pilot hops into the cockpit and rolls into the dome on the track. *Clack. Clack. Clack.* Once inside, the projectors shoot Google Earth-quality images of clouds and shadow, mountain ranges rushing past, dusty neighborhoods 30,000 feet below. There are rural landing strips, enemy jets ahead, and missiles whizzing your way. It's an immersive 360-degree view—with sound effects.

Like the F-35s themselves, the simulators are connected to a secure ground server and linked to each other. That way pilots can train together, in separate rooms, on tactical missions. These sims will one day be linked to other fighter-jet simulators at Air Force training bases around the U.S.

And that's where it gets interesting. Hierlmeier is a student of technology, and grew up reading science fiction and watching *Stars Wars*. Standing outside the cockpit, he peers into the darkened dome, and says he believes we will one day fight our enemies from inside one of these things. When I ask what that will take, he says flatly, "Bandwidth."

Bandwidth is a big challenge to networked warfare. And flying a fighter drone from the ground requires sending and receiving massive amounts of data in real time. So engineers are focused on things like improving artificial intelligence so planes can act with more autonomy, thus cutting down on communication bandwidth. If we get machines to think for themselves, we can equip them with a mission objective, rules for engagement, battle scenarios, and then send them on their way. Only by solving the problems of AI and operations autonomy, and onboard processing, says Ruszkowski, can we "reduce communications congestion and usage bandwidth." Skunk Works has demonstrated that with automated ground-collision avoidance and airborne-collision avoidance systems. If Ruszkowski and his team can extend those capabilities to next-gen stealth fighters, he says, it would go a long way to solving the problem: "We believe that's the foundation for future military systems."

Hierlmeier, flanked by a pair of Lockheed Martin contractors and an Air Force PR person tapping her smartphone, leans on the cockpit and considers that future. "I don't want to be the horse cavalry guy at the start of World War I," he says. "I'm hoping we'll see a day when man is not in the machine, in the jet, but man is in the loop. We've got to embrace that. I see a day when you're driving into this dome, and you're fighting the fight from right here." 📱

We stop at a double door the size of a loading dock. Hierlmeier opens it onto what looks like an amusement-park ride. A white dome, 11 feet in diameter, sits in the middle of the room, surrounded by a massive steel frame and 25 high-definition projectors. A replica F-35 cockpit sits on tracks that disappear into the dome. I ask if I can take a picture. No, says Hierlmeier. But he does invite me to sit in the cockpit, which I do. It's like sitting in a low-riding Italian sports car. Before they ever get to fly an actual F-35, the student pilots must first spend a month in class practicing on computer monitors with joysticks. Then they do 30 hours inside these simulators, helmets on. Those

**Air Force Lt.
Colonel Rhett
Hierlmeier trains
F-35 fighter pilots.**



THE FUTURE OF MONEY

CURRENCY HAS GONE FROM COWS TO COINS TO PAPER TO PLASTIC. THE NEXT BIG DISRUPTION? WE COULD ALL BE SPENDING DIGITAL DOUGH.

by KASHMIR HILL



T

THE NEXT TIME you pull a tattered \$5 bill out of your pocket to pay for a coffee, consider the fact that you're handling one of society's oldest and most important inventions: money.

Relatively soon after humans decided that we liked living in groups, instead of in panda-style isolation, we came up with ways to value what we had—and make people pay for it. We bartered cattle and grain until the Lydians—the Bronze Age inhabitants of what is modern-day Turkey—realized those were hard to stuff into a wallet, and introduced government-minted coins. It turned out coins were still a pain to carry around, so eventually they evolved into the paper money we all use today.

But paper was still just a stand-in for metal: Sure, coins mostly disappeared, but we were symbolically carrying gold around in the pockets of our bell-bottom jeans until 1971, when Richard Nixon took the U.S. off the gold standard. Divorced from the physical, money

became a kind of belief system. It went from representing something precious and valuable to representing value in and of itself. Everyone agrees that if you walk into Starbucks with a \$5 bill, you can walk out with a latte.

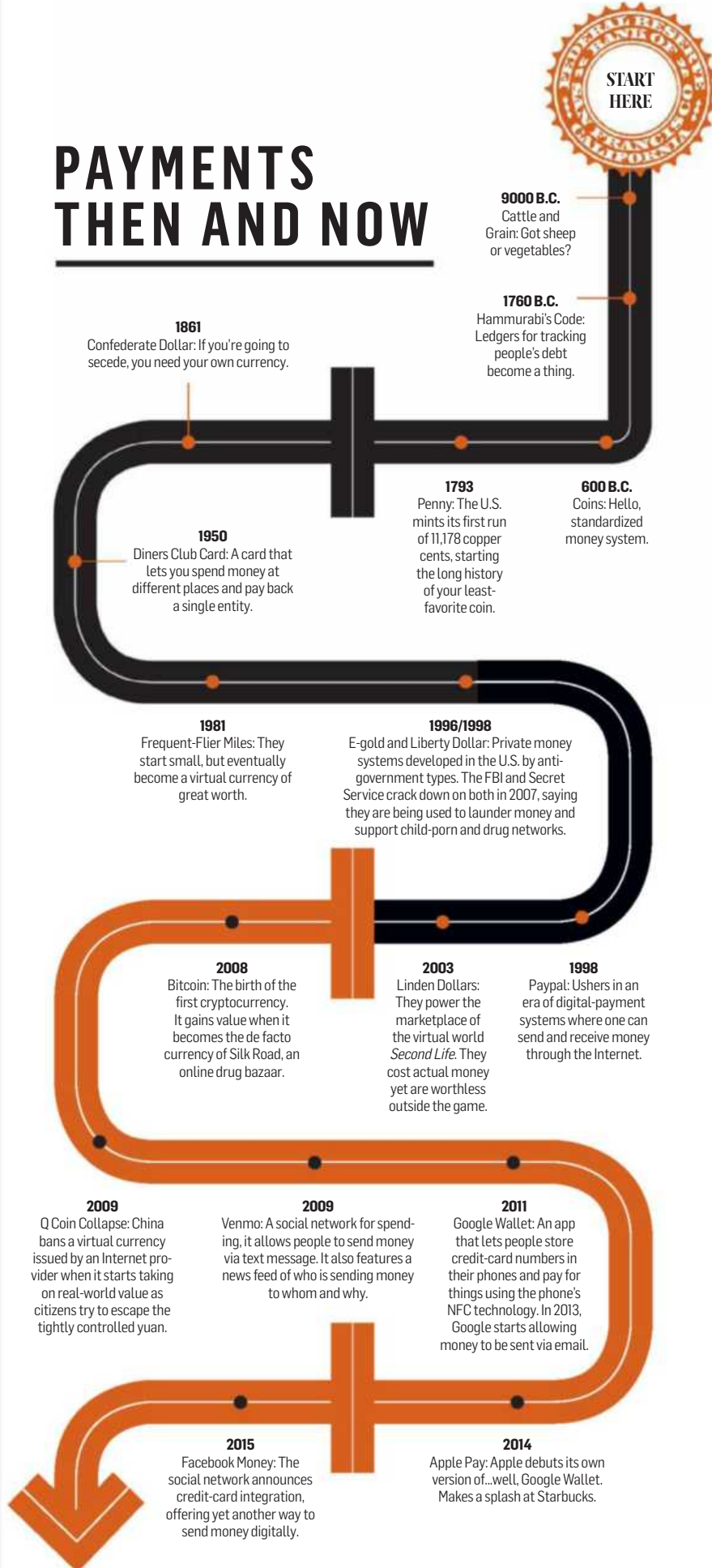
Of course, rarely do any of us walk into Starbucks with a \$5 bill anymore. We walk in with a credit card, or a Starbucks gift card, or with an Apple Pay app on our iPhone. And that's another way money has changed. It's become more and more abstracted. It's numbers sitting in our bank accounts or on our credit-card statements. It's a series of digital ledgers kept by banks, payment processors, and financial startups. The USA Network's *Mr. Robot* imagines the fragility of that system. The plot follows hackers who planned to break into the servers of the country's biggest lender and erase all the data—obliterating debt and ushering in a new anarchic, moneyless society.

Money grows more complex by the day, particularly now that Silicon Valley has taken it up as one of its causes célèbres. Startups offer dozens of schemes to disrupt it. Yet, Silicon Valley, which has changed the world in so many fundamental ways, hasn't actually changed money that much; it's just evolved how we spend it. Paypal, Square, Stripe, Venmo—they're all apps built on top of the old technology that is money. Just as paper once required metal, most payment apps require a bank account or a credit card.

The only true disruption to money that we've seen in the Internet age came not from a Palo Alto garage but a list-serv for tech-savvy libertarians. Bitcoin, which spun out of the mind of the pseudonymous engineer Satoshi Nakamoto in 2008, is a cryptographically maintained currency with value imbued by the computers of its users, not a government mint. Theoretically, it is far more secure than credit cards. If you used Bitcoin to buy something at Target, say, and Target later got hacked (possible, as we have learned), you'd suffer no consequences. It's like programmable cash.

But that's not a concept most people can get their heads around, which has been Bitcoin's great limitation. It might overcome that hurdle, or it might not. The only certainty is that money will keep evolving. If money represents value, and value is a reflection of our needs and desires, then money is simply a reflection of us. And it will continue to change as long as we do.

PAYMENTS THEN AND NOW



What is it?

In 2008, a programmer issued a white paper in which he argued that we need an Internet currency not subject to the fees and permissions of third-party intermediaries. So he came up with the digital equivalent of cash online, a system that lets participants send value to anyone else with a Bitcoin address the same way they might send an email. "Like the Internet flattened global speech, Bitcoin can flatten global money," says computer scientist Nick Szabo, who is suspected as Bitcoin's pseudonymous creator, Satoshi Nakamoto.

How do you make it?

That's the weird thing about Bitcoin—it's still being created. Every 10 minutes, new Bitcoin enter the system. "Miners" donate spare or dedicated processing power to help validate transactions around the globe. Bitcoin come as rewards for that work. In the early days, you could just do this with a PC. Now the process is complex and requires powerful hardware.

How do you use it?

If you want to own Bitcoin, you have to first get a Bitcoin address (like opening an email account so people can send you email). Blockchain.info is the best place for that, and then you have to either get someone who owns Bitcoin to give you some or buy it from an exchange like coinbase.com. When you own Bitcoin, you're assigned a value and a cryptographic key. With the key, you're the only person able to transfer that value to someone else.

How does it hold value?

When Nakamoto designed the Bitcoin software, he programmed it so it would create only 21 million Bitcoin, doled out slowly to the computers that joined the network. In limited supply, Bitcoin became not just a new way to send money but a much coveted one. There are now nearly 15 million Bitcoin worth more than \$5 billion.

BITCOIN

What It Is, How It Works, How It Lives, and How It Dies

What are the benefits?

The first is unobstructed speed. Money is sent immediately, and no one can stop it. When Visa and Paypal refused to transact payments to Wikileaks in 2010, so as to not support its release of classified government documents, donors sent \$32,000 in Bitcoin. The second is that it's built for the Internet, and that could make commerce a much better experience. Credit-card transactions will disappear, making the whole process more streamlined and efficient. Web-based businesses will be able to capitalize on that too. "Crappy things companies do now to monetize—banner ads, captchas, spam emails—will go away," predicts Fred Ehrsam, CFO of Bitcoin wallet Coinbase.

What stops Bitcoin from taking over?

Banks are skeptical of Bitcoin. With no government backing it up, they worry its value could crash at any moment. Also Bitcoin would end if its cryptography were broken (the NSA is probably working on that). The biggest challenge for Bitcoin, though, is that it's still associated with and used by a criminal element. It grew in prominence on Silk Road. Now it's a favorite of digital extortionists, who capture and encrypt a computer's contents, and threaten deletion without payment, usually in Bitcoin. Ransomware victims paid \$18 million last year, according to the FBI.

What are the drawbacks?

Bitcoin is not intuitive. It takes more than 10 minutes to explain. It can be stolen from you if someone steals your cryptographic keys. And it can be lost or destroyed. If you misplace the keys needed to unlock your entry on the Bitcoin ledger, say by wiping your hard drive or discarding it, you lose your Bitcoin. People call these "zombie coins," and one analysis estimated that 25 percent of Bitcoin are zombified, a loss of more than a billion dollars.

3 THINGS TO KEEP IN MIND BEFORE YOU BUY BITCOIN

- 1** Don't invest unless you have money to lose. Originally worth pennies, Bitcoin surged past \$1,000 apiece in fall 2013 but has hovered around the \$200 to \$400 mark for the past year.
- 2** Safe-keeping is key. If your Bitcoin get deleted or stolen, they're gone forever.
- 3** Prepare to keep clean books. As with stocks, the IRS requires you to report the gains (or losses) on every Bitcoin transaction, comparing the value of when you spend it to that of when you bought it.

CAMERON AND TYLER WINKLEVOSS ON THE APPEAL OF CRYPTOCURRENCIES

Best known as the maligned twins in the Facebook origin story, Cameron and Tyler Winklevoss are hoping to gain attention for being involved in another possible Internet giant: Bitcoin. They adopted it early, back in 2012, when cryptocurrency was still a fringe concept. In October, they got approval from financial regulators to launch their own U.S.-based exchange: Gemini. Here's why they have bet that Bitcoin will go big.

T: We are fascinated with Bitcoin because it is the first iteration of money that's actually built for the Internet, by the same type of engineers who built the Internet itself.

C: It sends payments over protocols, the same way we send data and voice today.

T: With just a cellphone and a Bitcoin address, you now have a bank account. You have a way to accept payment. You have a way to store value that isn't your mattress.

C: How it'll affect your life in the U.S. might be substantially different than in another part of the world. If you're in Argentina, and there's currency debasement of 25 to 30 percent a year, Bitcoin is sort of like disaster insurance. Plus you don't have to give over a lot of personal information to a retailer like you do with a credit card, so things like identity theft and consumer protection are actually improved.

T: Early Bitcoin operators, like Silk Road, definitely did it a disservice. But the irony is that Bitcoin is not good for illicit behavior. We know that because Silk Road was busted. And then two of the federal agents who made the bust and embezzled some of the Bitcoin were arrested too. The provenance of every coin—where it's traveled, what marketplace it's been on, what addresses have touched it—is all transparent and completely public.

C: So how's it going to affect your day-to-day? Through transactions we can't even contemplate right now.

T: Things like property deeds and title insurance could be moved to a blockchain-type transaction, such as Bitcoin. Computers and self-driving cars can't go open up a bank account at JPMorgan or Wells Fargo, but they can plug into protocols. So if your power meter needs to purchase more energy, you can program it to do that with Bitcoin. The fact that the government is now regulating Bitcoin shows it understands that the currency is hugely transformative. This decentralized blockchain-type technology is here to stay. And it's going to completely rewire the way the Internet works.

as told to **BREANNA DRAXLER**

THE EMERGING BITCOIN ECOSYSTEM

Nearly a billion dollars in venture-capital funding has flowed into Bitcoin companies to date, most of it since the price of a Bitcoin cracked \$1,000 in late

2013. More than 100 firms have sprung up to service—and profit from—Bitcoin. They're creating a new financial landscape for cryptocurrency. **KATIE PEEK**

TOTAL VENTURE-CAPITAL INVESTMENT BY TYPE OF FIRM

PAYMENT PROCESSORS

\$78 million
These companies, such as BitPay, provide the software for shops to accept Bitcoin payments.

EXCHANGES

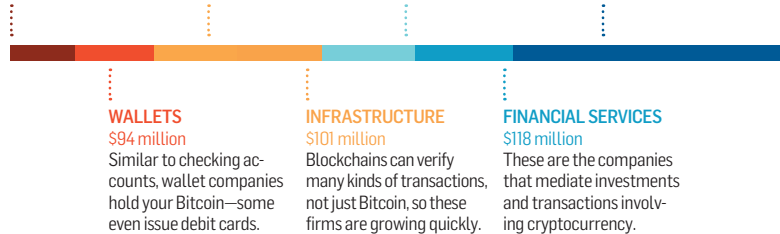
\$98 million
Like traditional exchanges, these companies provide a platform for buying and selling Bitcoin.

MINING OPERATIONS

\$112 million
These firms create new Bitcoin by supplying computational power for the blockchain.

UNIVERSAL FIRMS

\$322 million
Outfits that provide multiple Bitcoin services have drawn the most venture capital thus far.



WALLETS

\$94 million
Similar to checking accounts, wallet companies hold your Bitcoin—some even issue debit cards.

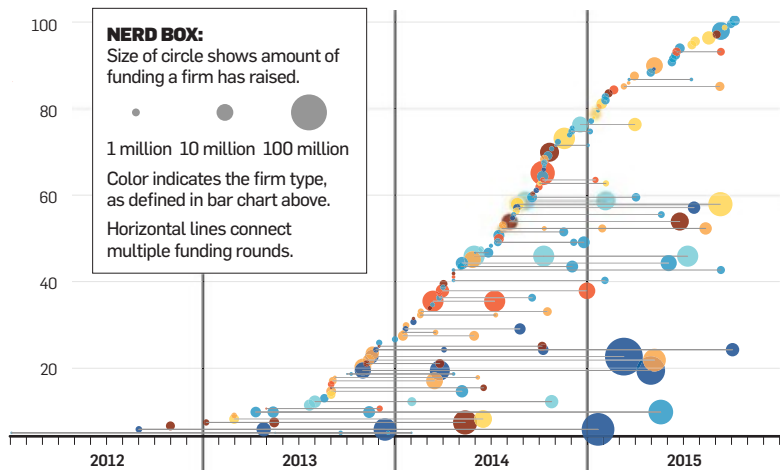
INFRASTRUCTURE

\$101 million
Blockchains can verify many kinds of transactions, not just Bitcoin, so these firms are growing quickly.

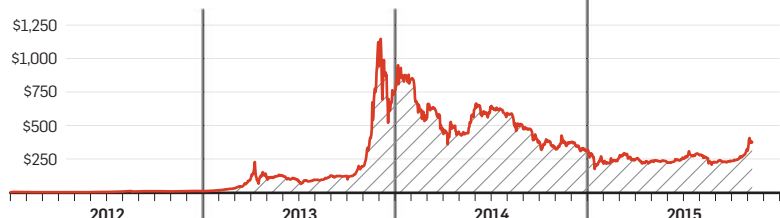
FINANCIAL SERVICES

\$118 million
These are the companies that mediate investments and transactions involving cryptocurrency.

NUMBER OF BITCOIN COMPANIES WITH PUBLICLY DISCLOSED FUNDING



THE VALUE OF 1 BITCOIN IN U.S. DOLLARS



SOURCE: COINDESK.COM

NOW, FOR A REALITY CHECK



I **IF YOU'RE NOT** a math genius or a cryptographer, it can be hard to wrap your head around what Bitcoin is. So two years ago, I decided to get familiarized by immersing myself in it. I got rid of my cash and credit cards, and spent a week in San Francisco living on Bitcoin. At the time, few people had heard of the cryptocurrency, and fewer actually accepted it. I couldn't pay my rent. I had to

walk or bike everywhere. The only food places that took it were a sushi restaurant, a cupcake shop, and a grocery store, which were all miles away (I lost 5 pounds in a week). It was hard, but I got to know the fervent libertarians, entrepreneurs, crypto-geeks, and fringe economists who were part of Bitcoin's then-small community. They so desperately wanted their radical currency to succeed, and they were worried at the time that the U.S. government might ban it.

A year later, in 2014, I repeated the experiment and had a completely different experience. Venture capitalists had discovered Bitcoin, pouring money into startups that made it easier to use. Intense interest from China sent Bitcoin's value over \$1,000, minting many of those early cryptogeeks into multimillionaires, at least on digital paper. Businesses had learned that accepting Bitcoin was an easy way to get press. So I was able to use Bitcoin to go on a wine tour of Santa Cruz and eat a 14-course dinner at a hip new restaurant. I even visited a strip club, where I convinced the exotic dancer to create a Bitcoin wallet while I watched.

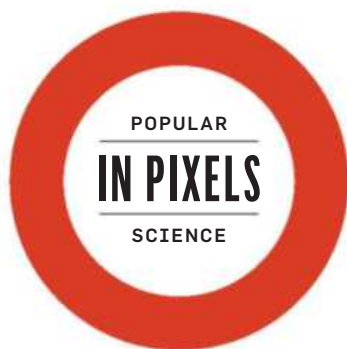
For many early adopters, this was all a bit depressing; their indie band had gone mainstream. China had mining operations with hundreds of servers. The venture-capital firm Andreessen Horowitz was funding a secret mining company. Most people no longer focused on how Bitcoin could free us

"I even visited a strip club, where I convinced the exotic dancer to create a Bitcoin wallet while I watched."

from government monetary control. Instead, they talked of how it could be better regulated to power the robot-to-robot transactions just over the horizon.

That future might be coming, but it's slower to arrive than most enthusiasts think. Even a year later, if I tried to live only on Bitcoin for more than a week, I'd either be very hungry or very bored with my meal options. And that's really the central issue with Bitcoin: Unless it becomes even easier for consumers and vendors to use, it could still become the Apple Newton of money—an incredible technology that flops. 





PROTO HEROES

One day robots could come to your rescue.
But first, they have to learn to walk.

PHOTOGRAPHY BY F. SCOTT SCHAFER

In 2012, DARPA announced the most ambitious robotics competition in history. To kick-start the development of robotic first responders—machines capable of deploying to natural or man-made disasters—the Pentagon's research agency proposed

a series of challenges. Robots would be tasked with navigating and interacting with a mock disaster site. They would open doors, traverse rubble, climb stairs, and turn valves. At times, they would have to act with almost complete autonomy in order to simulate communications breakdowns in a real-life crisis.

Teams from around the world entered the two-year competition. The Pentagon gave some of them multimillion-dollar robots to program, while others received funding to develop their own machines. But despite the generous allotted time and resources, the DARPA Robotics Competition (DRC) would be extremely difficult. Legged robots, by far the most common design in the contest, are notoriously unstable, even when crossing level terrain. For most teams the concern was not winning the DRC. It was surviving it.

The DRC finals were held in June at the Fairplex fairgrounds in Pomona, California. And, sure enough, many robots were hauled away from the two-day event in pieces. Falls were rampant, and every tumble drew sympathetic howls from the thousands of spectators watching from the stands. One humanoid fell so hard, its head flew off its body.

In the end, three teams won a combined \$3.5 million in prize money by completing eight tasks in less than an hour. But more to the point, the DRC served as a catalyst for robotics development. It forced many of the world's leading roboticists to tackle some of the field's hardest problems. None of the entries left the competition ready to respond to the next big disaster. But thanks to the DRC, the dream of robots that can function in the human world, whether that means pulling victims out of harm's way or simply assisting the elderly, is closer than ever. **ERIK SOFGE**

WALK-MAN →

ITALIAN INSTITUTE OF TECHNOLOGY AND
UNIVERSITY OF PISA

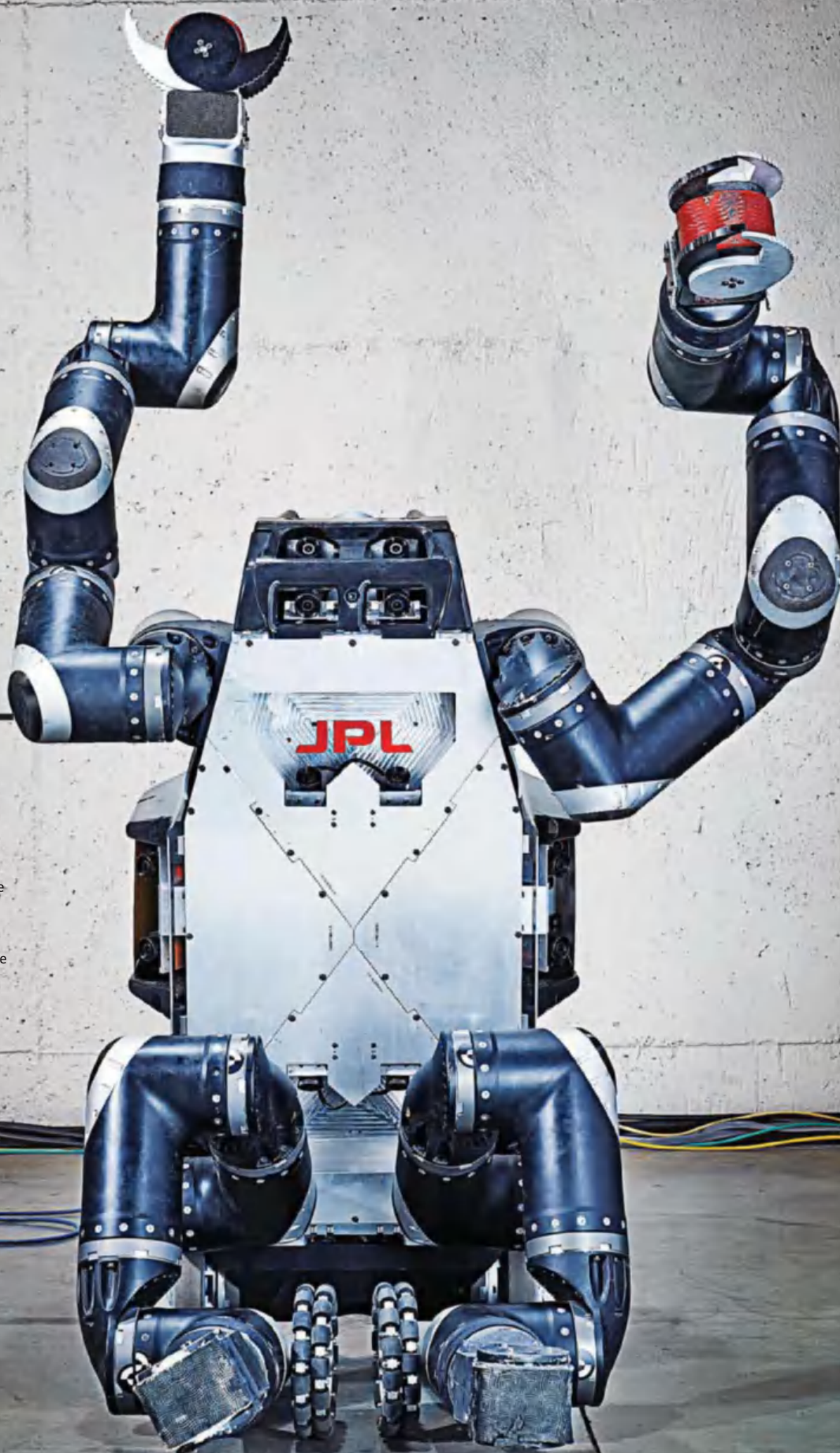
Faced with human-centric tasks, such as driving a vehicle and operating power tools, most teams in the DRC built humanoid robots. And since two-legged designs are prone to falls, roboticists armored this 6-foot-tall, 264-pound machine with strategically placed shock-absorbing pads.



RoboSimian

JET-PROPULSION
LABORATORY

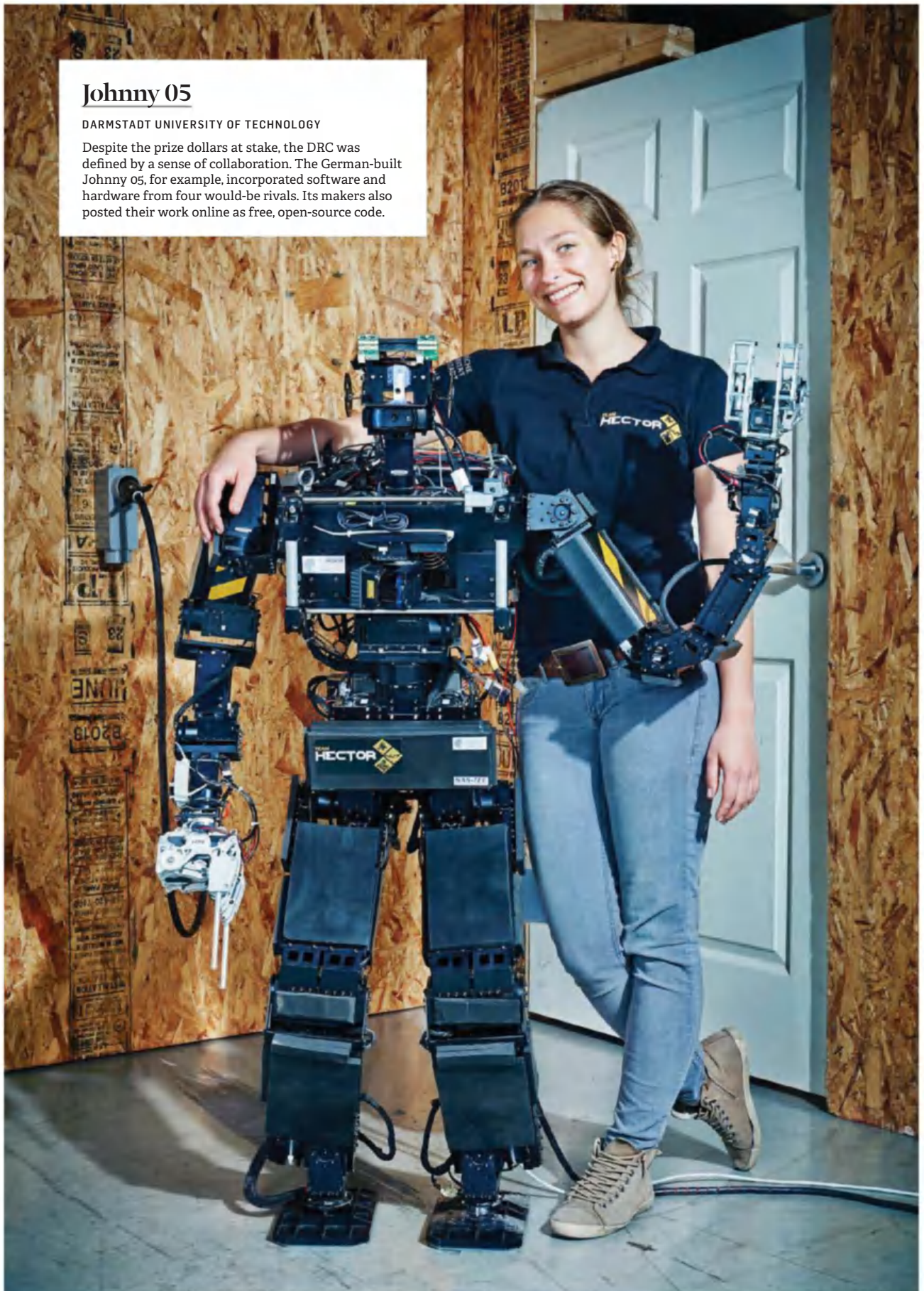
NASA claims that its entry was primate-inspired, but RoboSimian's defining feature isn't even mammalian. Each of its four limbs has 28 joints, giving the 275-pound robot a degree of flexibility that more closely resembles an octopus's tentacles than an orangutan's arms.



Johnny 05

DARMSTADT UNIVERSITY OF TECHNOLOGY

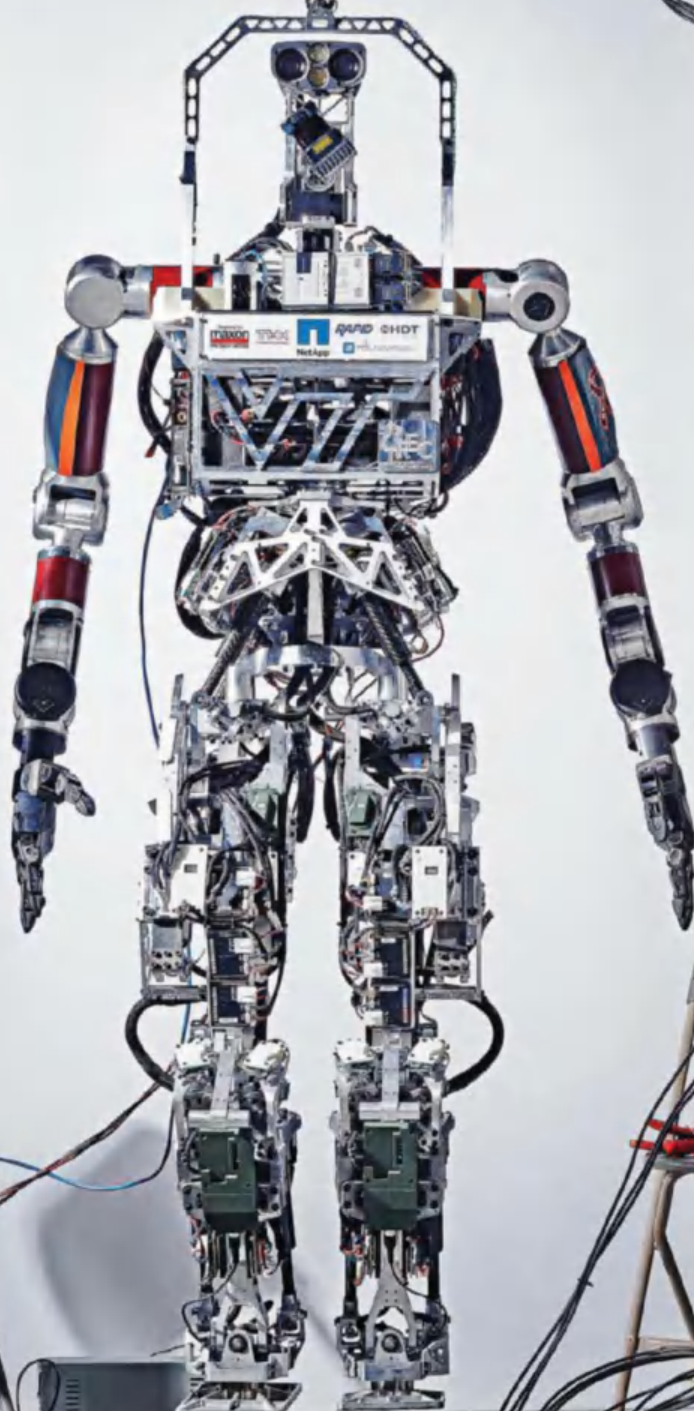
Despite the prize dollars at stake, the DRC was defined by a sense of collaboration. The German-built Johnny 05, for example, incorporated software and hardware from four would-be rivals. Its makers also posted their work online as free, open-source code.



ESCHER

VIRGINIA TECH

The engineering highlight of this 5-foot-10-inch bot is its series-elastic joints. By compressing and recapturing kinetic energy with each spring-loaded step, Escher's actuators mimic the combination of efficiency and shock absorbance found in human joints.





DRC-HUBO

KAIST AND RAINBOW CO.

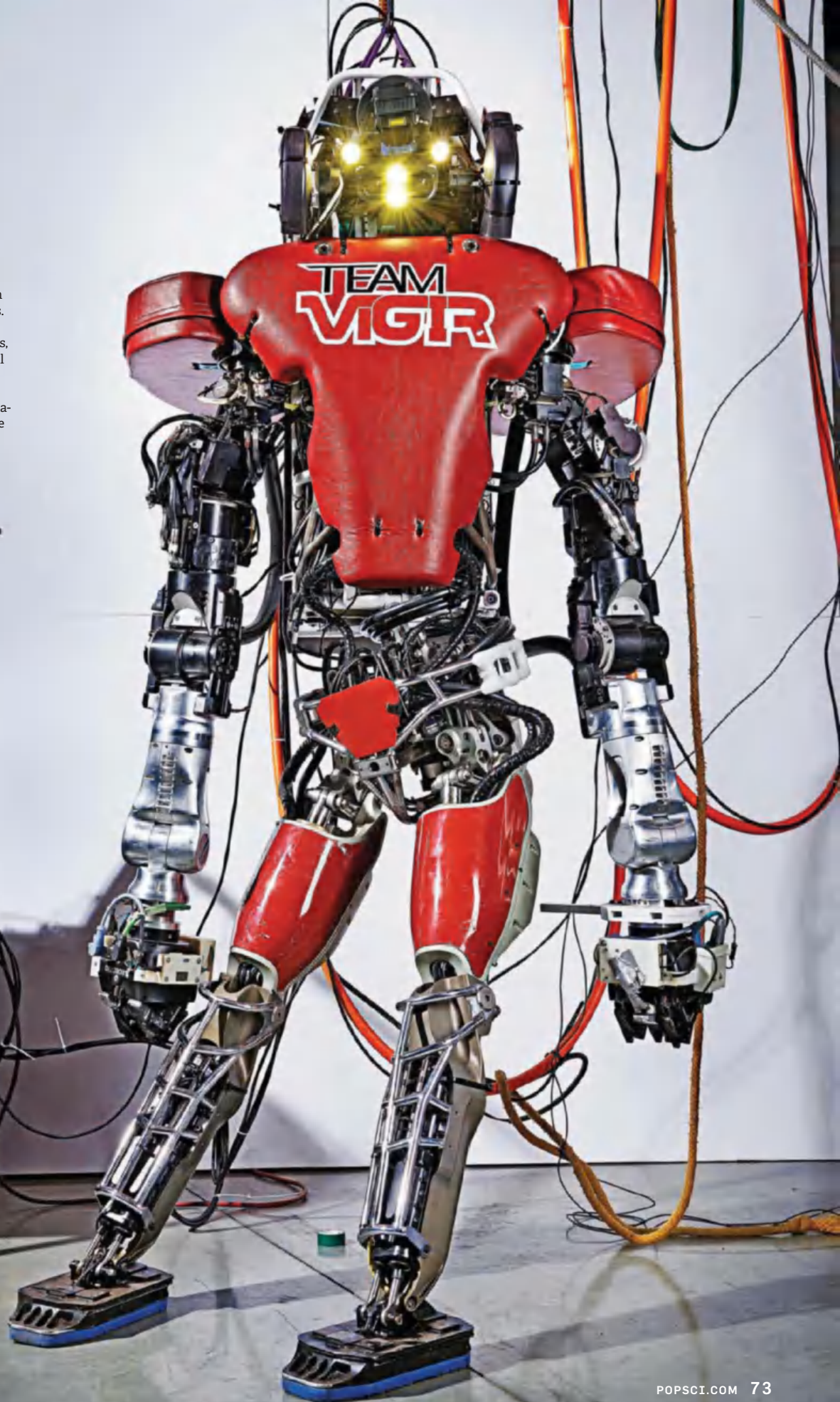
The top prize of \$2 million went to a humanoid from South Korea whose combination of dexterity and mobility—it could roll around on wheeled knees—trounced the competition. It could also grab the utility vehicle's roll cage in order to swiftly dismount from it, a task that slowed or destroyed other robots.



Florian

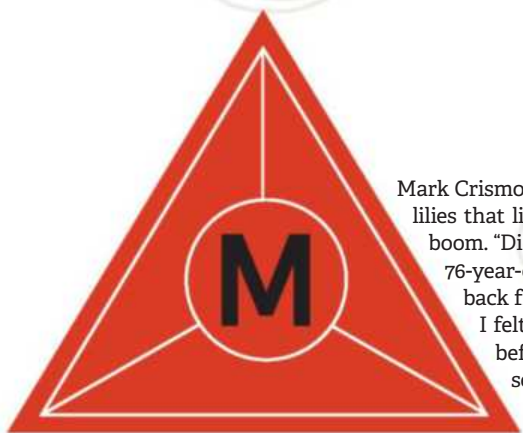
TEAM VIGIR

Florian was one of seven Atlas robots in the finals. The Pentagon provided them to qualifying teams, such as the international Team ViGIR. Although its members could make minor hardware modifications, the main challenge was to write software that kept the towering, 6-foot-2-inch machine from faceplanting while crossing uneven terrain.



Earthquake Nation

Last year, scientists had for seismic activity in the There's a whole lot more in the Midwest—and hum



Mark Crismon and I were sitting outside his Oklahoma house, looking at the day lilies that lined his pond, when our conversation was interrupted by a distant boom. “Did you feel that?” Crismon asked. “Just be quiet. Sit still.” He’s a lanky 76-year-old, retired from an electronics career, with gray hair combed straight back from his ruddy face. The booms continued, once or twice per minute; I felt them under my skin. “That’s a small earthquake,” he said, seconds before the sound recurred. “There it was again. We’ll go and look on the seismometer—I’ll show you what it looks like.”

We walked into his garage. It was July and approaching 100 degrees in the countryside north of Stillwater. The building was filled with freezers where Crismon and his wife store the food they grow, catch, shoot, and smoke. Deer and coyote tails covered corrugated-tin walls. On a desk in the corner, beside a hand-labeled bottle of peach brandy, sat a Dell laptop connected by a cable to a buried seismometer. Oklahoma State University scientists had given Crismon the seismometer in 2014, as part of a project to monitor the state’s current rash of earthquakes.

He took a drag from his cigarette, then turned his attention to three parallel bars scrolling across the screen: blue on the bottom, red in the middle, green on top. They were mostly straight but had become jagged for the several minutes we had felt the tremors.

By Barry Yeoman

to redraw the map United States. shaking going on ans are causing it.

"How'd you like to put up with that day and night?" he asked.

Crismon sits at this desk, on and off, for 14 hours a day. He arrives at 6 in the morning and takes pictures of the spikes with a digital camera to document what he calls a growing menace (even though the data gets recorded regardless). There's plenty to photograph: Oklahoma, which historically has had few earthquakes of magnitude 3.0 or higher, started rumbling regularly in 2009. The Oklahoma Geological Survey recorded 35 such quakes in 2012, 109 in 2013, and 584 in 2014. (The prior annual average was fewer than two.) By late October, the 2015 figure had already exceeded 700.

Scientists have figured out the reason: the oil-and-gas industry's practice of

injecting wastewater deep underground.

The granite basement that underlies the continent, a mile below Oklahoma's wheat and alfalfa fields, is full of faults. Usually, natural stresses clamp the rocks and keep them from moving—like "a vise that's slammed on the east and west side, and someone's turning the screw," says

Todd Halihan, a hydrogeophysicist at Oklahoma State University. Inject fluid deep enough, he says, and it travels into the fractures in the granite, in effect lubricating the rock and causing faults to slip.

Halihan compares this to tabletop air hockey. "When it's off, the puck doesn't move particularly well," he says. "Turn on the air, and it's like you're injecting. That puck moves *real* well."

It's not only in Oklahoma where we're giving the proverbial puck more room to slide. Our species, unintentionally, keeps

finding new ways to unleash earthquakes. We have rattled the ground by impounding reservoirs, excavating mines, testing nuclear weapons, tapping geothermal power, and pushing carbon dioxide underground to slow global warming.

Sometimes these quakes arrive as jolts like those Crismon and I felt outside his house. Sometimes they topple buildings and claim lives. Whether they hit the Midwest, California,

Switzerland, India, or China, some of those who feel the shocks are asking: Can we control the tremors, or are damaging quakes an inevitable feature of the future?

 **We first recognized** the problem of man-made earthquakes around the turn of the 20th century, as they began hitting the regions around South Africa's gold mines and Europe's coal mines. The release of gravitational energy, when the rock above the mines sagged, triggered them.

It took until the 1930s for Americans to notice man-made quakes beneath our own soil. When engineers created Lake Mead behind the Hoover Dam, the sudden addition of 12 billion tons of water apparently set off hundreds of small tremors along the Arizona-Nevada border. "This was an 'aha moment,' an important benchmark in the science," says Bill Ellsworth, an emeritus seismologist with the U.S. Geological Survey and geophysics professor

at Stanford University. Since then, reservoirs have been linked to devastating quakes around the world: definitively to a magnitude-6.3 quake that killed 200 people in 1967 near India's Koyna Dam, and more speculatively to the 2008 Sichuan quake, a magnitude-7.9 colossus that flattened schools and hospitals in China, and left more than 80,000 people dead or missing. The Sichuan quake was triggered less than 6 miles from the Zipingpu Dam reservoir, says natural-hazards researcher Christian Klose, who has linked water levels there to tremor frequency.

The most ominous precursor to Oklahoma came in the 1960s, when a series of earthquakes walloped the normally quiet Denver area. During two particularly lively days in 1962, the shocks broke windows, cracked plaster, and left electrical outlets hanging by wires. "Children cried with fright," read a federal field report from Dupont, a town just north of the city.

Scientists traced this seismic uptick to the Rocky Mountain Arsenal, an Army facility that manufactured chemical weapons and rocket fuel. Weeks before the trembling began, the arsenal had started injecting wastewater 2 miles down into the crystalline basement rock. After the injections stopped, in 1966, it took a year for the shaking to cease: A magnitude-5.3 quake knocked bricks from chimneys in 1967 and caused more than \$1 million in damage.

A geologist named David Evans found an association between the amount of fluid injected at the arsenal and the number of earthquakes, and suggested cause and effect. (To demonstrate how lubricated rocks slip, Evans reportedly would perform the "Coors experiment": He perforated the bottom of a beer can, and then showed how the seeping liquid eased its slide down an incline.) The Army disputed Evans' hypothesis, but he was vindicated by USGS researchers, who triggered seismicity soon after by methodically injecting fluid into Colorado's Rangely oil field.

Since then, scientists have grown more sophisticated about documenting changes in earthquake activity. About 200 miles south of Rangely, in Colorado's Paradox



▲ Oil-and-gas operations produce wastewater made up largely of brine. Injection wells in the U.S. pump 2 billion gallons of it a day underground.

Valley, the U.S. Bureau of Reclamation has been injecting briny groundwater into a deep limestone formation in order to keep it from contaminating a river. "Somebody had the foresight to say, 'Let's see what kind of seismicity's out there *before* we start injecting,'" says bureau geophysicist Lisa Block. Six years of baseline data showed almost no natural activity. By contrast, the agency has recorded 6,200 quakes, most of them small, since underground disposal began in 1991.

By the time Oklahoma starting ramping up its own wastewater injection—now more than a billion barrels a year—the notion that humans can induce earthquakes by putting fluid underground was already familiar. Still, Sooner State residents were caught off-guard when that geologic principle hit home.

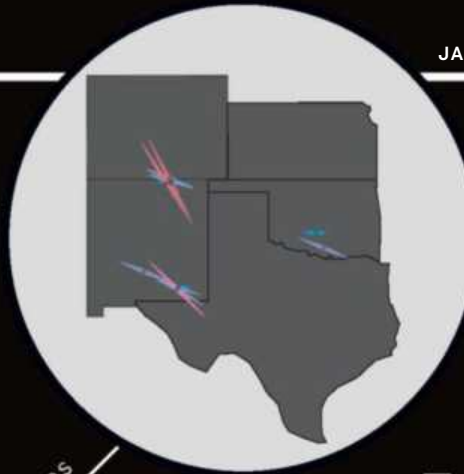
▲ **Todd Halihan was standing** in the hallway of his Stillwater home one night in November 2011 when he noticed glasses starting to rattle. As the building shook, the hydrogeophysicist flashed on his sleeping 6-year-old. "Should I get my kid out of bed and run out of the house?" he recalls thinking. "Should I get him under a table?"

Halihan was feeling the effects of a magnitude-5.7 quake—Oklahoma's largest, it turns out. Its center was near Prague (rhymes with "vague"), almost 50 miles away, where it buckled a highway and destroyed 14 homes. In one living room, rock from a fireplace and chimney struck a woman as she watched TV. The earthquake also toppled a historic turret at St. Gregory's University in nearby Shawnee.

Sometimes these quakes arrive as jolts like those Crismon and I felt. Sometimes they topple buildings and claim lives.

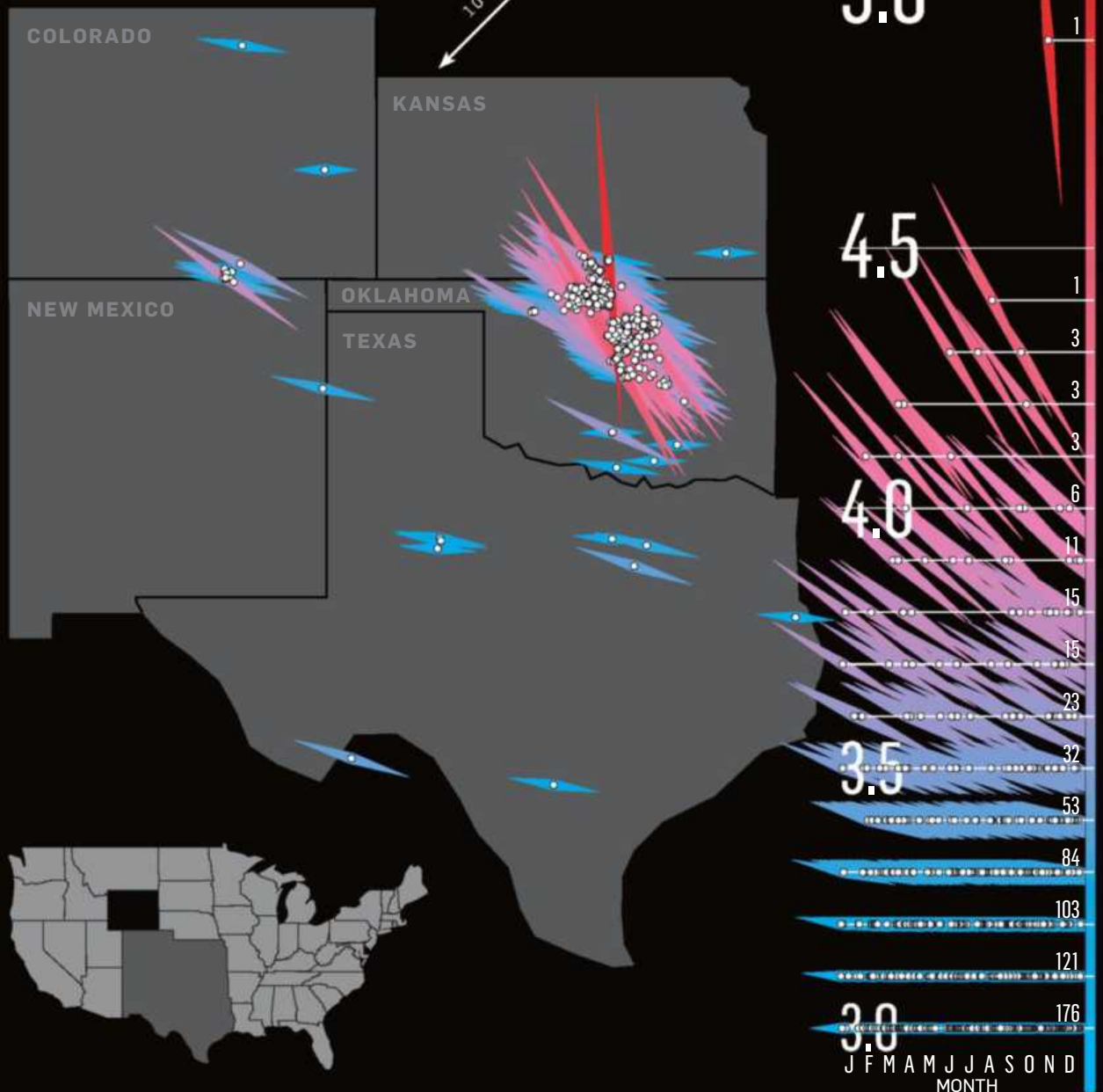
The Surge in Shaking

A decade ago, this part of North America experienced just 14 tremors a year. In 2014, 650 quakes hit the area, most of them clustered around wastewater injection wells.



NERD BOX:

Both maps show tremors stronger than magnitude 3.0. Color represents strength; dots mark centers. The map omits a few quakes along the west of New Mexico and Colorado, to avoid earthquake-prone mountain regions.



A team from the University of Oklahoma, Columbia University, and USGS determined the source: a fault rupture that began about 650 feet from active injection wells.

"That's when a lot more people started paying attention," says Austin Holland, Oklahoma's state seismologist until this past summer.

The idea that the oil-and-gas industry could be producing these quakes was a touchy subject, both for companies and for the administration of Gov. Mary Fallin. One study shows the industry has created one-fourth of Oklahoma's new jobs since 2010. Emails obtained by the EnergyWire news service paint a picture of a government that, in the words of Fallin chief of staff Denise Northrup, tried to "make this go away." Shortly after the Prague earthquake, Fallin aides contacted Devon Energy, an oil-and-gas producer, and obtained talking points to use with constituents. Among them: "There is no current evidence that oil-and-gas operations had anything to do with the recent large earthquakes in Oklahoma." When Fallin addressed a National Governors Association forum on shale-energy development in 2013, a reference to underground injection wells was deleted from her speech. "We had other issues we wanted to highlight," says Alex Weintz, Fallin's communications director until this past November.

Weintz says Fallin's personal views were always more nuanced than Devon Energy's talking points, even if those points were used by her staff. Her own reticence to blame disposal wells, he says, reflected the state of the research when she took office in 2011. "It was only the beginning of a spike in seismic activity," he says. "Since then, the science has evolved."

Even the Oklahoma Geological Survey, a university-affiliated state agency, was slow to acknowledge the disposal-well connection. In a 2013 statement, it noted that the Prague earthquake appeared to be the result of "natural causes." Holland, who worked for the survey, says, "Oil-and-gas is a very important industry, and so... some of the public statements saw a lot of wordsmithing."

As scientists dug into data, a consensus emerged that fluid injection was indeed behind the spike in earthquake

EARTHQUAKE NATION

activity. Even Fallin has come around. "We all know now there is a direct correlation between the increase of earthquakes that we've seen in Oklahoma and the disposal wells," she said at an August meeting of her administration's Coordinating Council on Seismic Activity.

In fact, new research shows earthquakes now pose a risk to the oil-and-gas industry itself. The largest crude-oil storage facility in the world sits in Cushing, Oklahoma, right above a fault recently activated by injection. Continued injection could produce a magnitude-5.7 earthquake, large enough to rupture oil tanks and pipelines.

The problem doesn't stop at Oklahoma's borders; man-made earthquakes have hit other midcontinent states too. On New Year's Eve 2011, a magnitude-4.0 tremor in Youngstown, Ohio, shook buildings and led to the shutdown of a disposal well that was deemed the likely culprit. Waste injection has also been linked to quakes in Arkansas, Colorado, Kansas, New Mexico, and Texas.

If the same quakes had happened overseas, they might have caused far more damage. "The technologies that have been pioneered primarily in the U.S.—to unlock gas from tight shale and to produce

The problem doesn't stop at Oklahoma's borders; man-made earthquakes have hit other midcontinent states too.

oil from unconventional reservoirs—have the potential to be applied around the world," says Ellsworth, the USGS seismologist. "Many countries will find it irresistible to produce their own resources. Unfortunately, in many of these countries, the building standards are not what they are in the United States, and the potential for severe damage and loss of life is really high."

▶
Mark Crismon monitors earthquake activity caused by injection wells at his home in Oklahoma, as part of a seismic network set up by scientists.



▶
As we keep using the earth as a vault to stash our waste—and as a tappable resource—we're creating a global-energy system that will likely increase the risk of small and potentially large earthquakes. Engineers will need to weigh every resource, looking at how much power it provides, how green it is, and what type of seismic risk it poses.

In some cases, the technologies we've engineered to ease our impact on the environment have proved likely to shake the ground. In a pilot

The Case for Human-Caused Earthquakes, in Charts

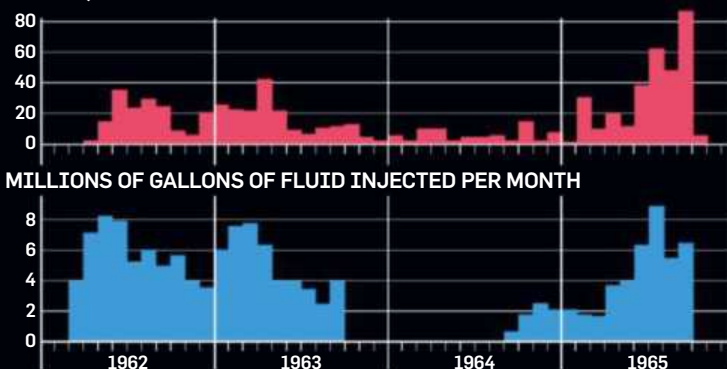
by
KATIE
PEEK

1

Do injection wells really cause earthquakes?

Yes. In the early 1960s, an area near Denver experienced a cluster of 710 earthquakes. The tremors started a month after the Rocky Mountain Arsenal installed an injection well to dispose of waste from chemical-weapons manufacturing. Before 1960, the most recent earthquake in the region had been in 1882. Careful statistical analysis confirmed a trend obvious to even a casual observer: Large volumes of liquid, shot deep into the earth, can cause the ground to shake.

EARTHQUAKES PER MONTH NEAR DENVER INJECTION WELL

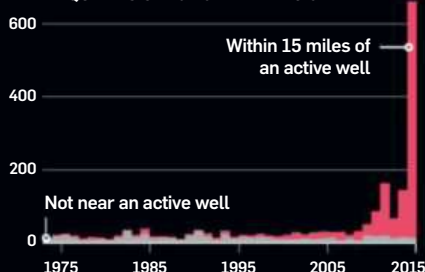


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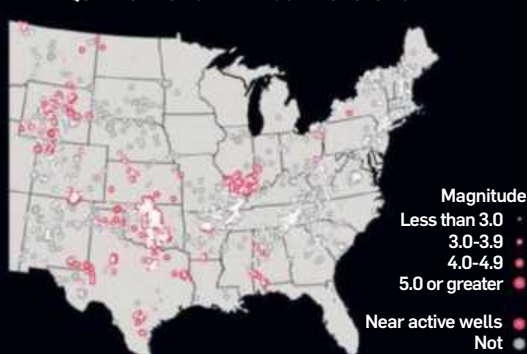
Are the recent quakes throughout the U.S. also caused by injection?

Almost certainly. In a recent study, published in *Science*, geophysicists analyzed earthquakes east of the Rockies and found a strong link to injection sites. Since 2011, 87 percent of tremors stronger than magnitude 3.0 have occurred within 15 miles of an active well.

EARTHQUAKES STRONGER THAN 3.0



EARTHQUAKES EAST OF THE ROCKIES 1973-2014



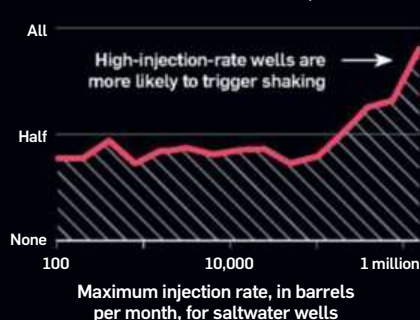
3

Can oil and gas companies prevent future earthquakes?

Probably. The authors of the *Science* study analyzed more than 7,000 earthquakes and nearly 20,000 wells to identify the practices most likely to be responsible. They found high injection rate was the biggest culprit, at least for saltwater wells. (Such wells inject brine into fresh ground, as opposed to enhanced oil recovery wells, which inject it into oil or gas fields in order

to extract fuel.) Injection rate mattered more than well depth or total fluid volume. It's a logical conclusion: Injecting fluid rapidly gives it less time to diffuse, which may raise the pressure that pushes rocks apart at a fault line. But many high injection rate wells operate in states such as Michigan without creating earthquakes, so the structure of the ground is a factor too.

FRACTION OF WELLS LINKED TO QUAKES





Hydrogeophysicist Todd Halihan says it might not take much pressure to increase seismicity—as little as 15 pounds per square inch. “Half of a car tire,” he says.

project in Decatur, Illinois, carbon dioxide captured from an ethanol plant is being injected, in liquidlike form, almost 7,000 feet down into a sandstone formation. The goal is to slow climate change by keeping the greenhouse gas out of the atmosphere (a tactic also advanced by proponents of “clean coal”).

So far, the injections have caused only the smallest of tremors, too faint to be felt. But Stanford University geophysicist Mark Zoback and hydrogeologist Steven Gorelick have argued that for underground carbon storage to benefit the climate, it must happen at a “massive scale”—one that will likely trigger more seismicity, and therefore potentially defeat its own purpose by discharging the carbon into the atmosphere. “Even small to moderate earthquakes threaten the seal integrity of a CO₂ repository,” they wrote in a 2012 journal article. For that reason, they concluded, carbon injection will be “an extremely expensive and risky strategy” to reduce greenhouse gases.

Ole Kaven—a USGS geophysicist involved in the Illinois project—says that if researchers can map faults, fractures, and fluid pathways using sophisticated instruments, they can reduce the hazard, though not eliminate it entirely. “If one factors in the cost of greenhouse-gas emissions, and what effect CO₂ sequestration can have on reducing some of the long-term effects, this conversation changes,” he says. “Some of these risks might be tolerated.”

That’s a critical point: A technology might produce

environmental damage. “If we could tap all the heat in the earth, we wouldn’t need anything else,” says Ernest Majer, a geophysicist affiliated with both the Lawrence Berkeley National Laboratory and Sandia National Laboratories.

That was no comfort in Basel, Switzerland, where in December 2006 operators of the Deep Heat Mining project began injecting cold water into the naturally hot granite below the city. The following week, a magnitude-3.4 shock rattled windows and cracked plaster. Injection was halted. A government study projected a 15 percent chance of a man-made earthquake causing more than \$500 million in damage if production resumed. In 2009 the project was scrapped entirely.

Geothermal production continues in rural areas—most notably at the Geysers, north of California’s Bay Area, where locals have routinely endured minor quake damage. “Sometimes it feels like a big truck just bumped into the house,” says Jeff Gospe, who sits on a seismic-monitoring advisory committee there. Neighbors have reported cracked windows and a retaining wall that crushed a van.

Majer believes that the hazard posed by geothermal fields is minor compared with their potential to produce clean energy. (He says the Geysers alone could power all of San Francisco.) “There’s no such thing as zero risk,” Majer says. “Driving to the grocery store is a risk. Everybody risks when they get out of bed in the morning.” Compare that, he says, with the cost of carbon emissions: “If you start looking at the health impacts, the climate impacts—all the nasty things

earthquakes, but what harm might come from not using it? Take geothermal production, a reliable and underused source of electricity that causes little

coming out of the fossil-fuel economy—well, maybe we better do something else. Induced seismicity associated with putting carbon into the ground, associated with geothermal: Those are minor, minor things compared with all these other risks facing us.”



Assuming we're not going to shut down energy production, scientists now face a more complex question: whether it's possible to minimize the hazard.

After the experiments in Colorado's Rangely oil field in the 1960s and '70s, which showed that we could control induced seismicity by varying the pressure of injected fluid, scientists were bursting with hope. Not only might they reduce damage from man-made quakes, the thinking went, but maybe they could control natural ones. Rather than waiting for the next bridge-toppler to hit California, USGS scientists suggested drilling wells along the San Andreas Fault, injecting water, and releasing the accumulated stress in a series of small, harmless quakes.

The idea never got traction. Not only would it take thousands of mini quakes to offset a major one, but it is also too risky. More than a century has passed since

It's not easy to talk when the ground is rattling. Each side retreats into a corner. The conversations grow polarized.

San Francisco's deadly 1906 quake, which means the city is sitting on highly stressed rock. Inject water underground, says Oklahoma's Halihan, and “you might not release 100,000 small ones. You might release a big one.” Even if the experiment did work locally, he says, “you might set off the next segment of the fault. It's 3-D and it's complicated: ‘Hey, we didn't cause an earthquake in San Francisco. ‘Well, you just knocked down LA.’ ‘Sorry.’”

Today, nobody's talking about setting off microtremors in Oklahoma in order to avoid the next Prague earthquake. But scientists are talking about more-modest ways to manage seismicity. “The toolbox is growing,” says Austin Holland, who now works for USGS in New Mexico. It includes avoiding known faults, scaling back the volume and rate of fluid injected into the rock, injecting at a shallower depth, improving monitoring, and preparing to abandon wells altogether if seismicity can't be stopped. This past year, the Oklahoma Corporation Commission—which regulates the industry—ordered volume reductions for some wells, as well as “plug backs” to limit how deep some wastewater is injected. The state's “traffic light” system, instituted in 2013, allows regulators to scale back or halt drilling in response to seismic activity.

Still, eight magnitude-3 and -4 quakes struck northern Oklahoma during a 24-hour period as this story went to press. There's a lot we haven't yet learned about what happens underground—and that knowledge gap stymies



A truck carrying wastewater dumps it into a storage facility in Oklahoma before it is re-injected into the ground.

us from managing the earthquakes we do create.

“Probably the greatest unknowns are the properties and processes deep within the earth, things that are very difficult to measure directly,” Holland says. “How is pressure being communicated? Do faults act as seals or as conduits? What are the actual stress states deep within the earth? That's where science has to spend a significant amount of effort and resources.”



Back in Stillwater, Todd Halihan understands both sides. He wants his students to find work in the energy industry when they graduate. But he also doesn't want to have to

dive for his son the next time an earthquake shakes his house.

“We're going to make some decisions, and none of them are going to be super-simple or super-pleasant,” he says. Ideally, that means talking levelheadedly about both the value of oil-and-gas production and the threat of earthquakes—how to balance those competing concerns and how much uncertainty we're willing to tolerate.

It's not easy to talk, though, when the ground is rattling. Each side retreats into a corner. Some industry and political leaders refuse to acknowledge the emerging science. Some quake-zone residents, feeling ignored and outgunned, pull out the only weapon they have: their rhetoric. The conversations grow polarized rather than solution-oriented.

Technology, Halihan says, often carries harm. “The *Titanic's* a nice example,” he says. “We were developing big ships, and we sank them. Developed airplanes; we crashed them.” Addressing unintended consequences doesn't necessarily mean scrapping innovations. Nor does it mean pretending the consequences don't exist.

With seismicity, as with addiction, the first step is admitting we have a problem that's not fully within our control. “The government, as well as these companies, should be upfront,” says Leonardo Seeber, an earthquake geologist at Columbia University's Lamont-Doherty Earth Observatory. “You want to drive your car. It takes gasoline. To produce that, you have to make wells. You have to pump in here and pump out there. And when you are doing that,” he says, “you are changing the stress in the subsurface. Sometimes there could be earthquakes that we can't predict. There could be consequences. But we're all in it together.” 🌋

Does “IN GOD WE TRUST”

BY: MIKE FULJENZ

Belong on Police Cars?

In the last few years, the phrase “In God We Trust” has elicited arguments between supporters and critics over whether the phrase belongs on public property. Those who believe in the “separation of church and state” (a phrase which is not in the U.S. Constitution) argue that God has no place in the public square. What they don’t realize is that the courts have ruled otherwise in numerous cases. The courts and Congress have said that “In God We Trust” would be historically appropriate, since it is our official national motto.

One of the more recent court cases resulted in a 2013 ruling by Judge Harold Baer, Jr of the United States Southern District of New York, who dismissed a lawsuit (Case 1:13-cv-00741-HB) filed by an atheist group (Freedom From Religion) and 19 other plaintiffs seeking removal of “In God We Trust” from coins and paper money. Judge Baer noted in his ruling that “the U.S. Supreme Court has repeatedly assumed the motto’s secular purpose and effect.” The judge also ruled that while the plaintiffs might feel offended at its presence, they suffered no “substantial burden” because of the motto’s appearance on U.S. money.

A similar case in 2011, brought by the same atheist attorney, Michael Newdow, went all the way to the U.S. Supreme Court, where it was rejected. Ironically, Newdow graduated from Brown University, whose motto since 1765 has been “In Deo Speramus” (In God We Hope). This certainly deflates the argument that this phrase (or versions of it) was only popularized during the Civil War or in the mid-20th century.

The phrase “In God We Trust” made headlines again in 2011, when the House of Representatives passed a non-binding resolution reaffirming its status as the U.S. national motto. It did so after President Obama mistakenly referred to “E Pluribus Unum” as America’s motto. That phrase – which means “Out of many, one” in Latin – has appeared on U.S. coinage for more than two centuries, but it enjoys no official status.

In one specific case, “E Pluribus Unum” was engraved on the new Capital Visitors Center until Congress ordered its removal in favor of “In God We Trust.” The aforementioned Congressional resolution drafted by Virginia Congressman Randy Forbes encouraged display of “In God We Trust” in all public schools and government buildings. It was approved overwhelmingly by a vote of 396 to 9 with two abstentions.

Most recently, we have seen the motto’s placement on police vehicles in some communities, with some vocal resistance coming from those who believe that this somehow violates the “establishment” clause of the First Amendment (“Congress shall make no law respecting an establishment of religion, or prohibiting the free exercise thereof”), which clearly prohibits the establishment of a certain “brand” of religion.

Webster defines “motto” as “a phrase that expresses a rule guiding the behavior of a particular person or group.” Florida’s state motto is also “In God We Trust,” and four states (Indiana, Kentucky, Florida and South Carolina) manufacture license plates with this phrase as a standard plate option for no extra fee.

Most critics of “In God We Trust” are ignorant of the phrase’s legal history or they ignore the many court rulings and resolutions of Congress in its favor. One version of the phrase appeared in Francis Scott Key’s 1814 poem, which was considered our national hymn in the mid-1800s before it became our official National Anthem in 1931. In the fourth and final stanza, Key wrote: “And this be our motto – ‘In God is our Trust!’” Exactly 50 years later, “In God We Trust” was first placed on circulating U.S. coins in 1864, and it has been on all coins since 1938. It became our official national motto in 1956, when President Dwight Eisenhower signed it into law, and it has appeared on all paper money since 1966.

The idea for adding this motto to U.S. coins began in 1861, when a Baptist minister from Ridleyville, PA, wrote Treasury Secretary Salmon P. Chase a letter urging “the recognition of the Almighty God in some form on our coins.” Chase (also a graduate of Brown University) agreed and instructed Mint Director James Pollock to prepare a motto “in the fewest tersest terms” recognizing “the trust of our people in God.” Pollock wrote back that he recalled the reference to such a motto in the fourth stanza of The Star Spangled Banner, our popular national hymn. Pollock added ‘GOD OUR TRUST’ on a few experimental pattern coins for proposed new designs. After consultation and debate in the Treasury Department, the words, IN GOD WE TRUST first appeared in circulating coins on a new copper 2-cent piece denomination in 1864.

With over 150 years of tradition, patriotism and law behind it – or 200 to 250 years, if you count Francis Scott Key’s poem which became the National Anthem, or the inscription at Brown University – it is safe to say that “In God We Trust” will likely survive any challenge as our national motto; the Star Spangled Banner will remain our National Anthem and In God We Trust will remain on law enforcement vehicles.

Known as America’s Gold Expert®, Michael Fuljenz’ writings on the National Motto have won awards from the Numismatic Literary Guild and the Press Club of Southeast Texas and been published on this topic in such diverse publications as the Baptist Message and Newsmax Finance. His detailed history of the national motto is available free online at www.INGODWETRUSTonmoney.com.

In addition, Fuljenz is a past president of the diocese of Beaumont Catholic school board and the 2013 Catholic Charities Humanitarian of the Year Award recipient. He serves on the Beaumont Crime Stoppers board and was the 2012 Beaumont Police Department Corporate Award recipient.



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Mike
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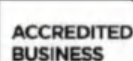


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by
**DAVE
PROCHNOW**

When a pile of snow falls overnight, the last thing you want to do is wake up early to shovel the sidewalk. With a radio-controlled snowplow, you won't need to. It does the work while you sip your morning coffee.

To make sure your plow will have

WARNING Water and electricity shouldn't mix. Use waterproof tape to keep snow out of the plow's main compartment.

sufficient muscle, start with the rugged Warden Robot Kit from Actobotics. Add a sealed gel-cell battery, electrically joined drive motors, and a shovel blade assembled from 3-D-printed parts. Steer your vehicle over the driveway using the remote, and you're ready for total winter domination—from the comfort of the indoors.

See photographs, a wiring diagram, and more at popsci.com/RCplow.

TOOLS



Hex keys
($7/64$, $9/64$,
and $3/32$)



Soldering
iron



Wire
cutter/
stripper



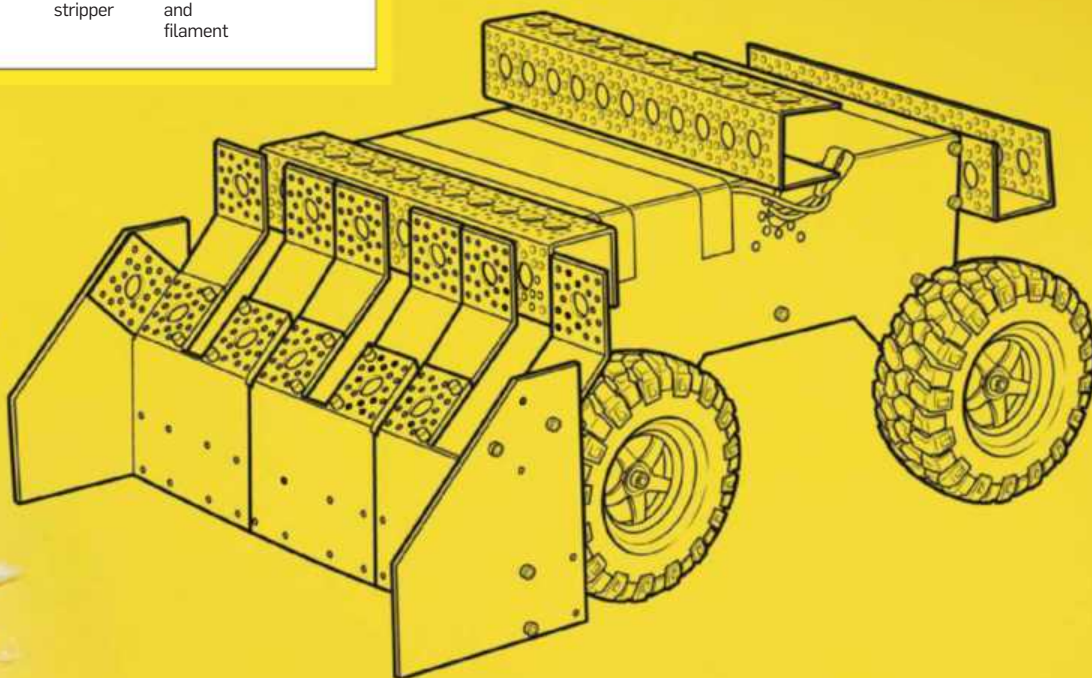
3-D
printer
and
filament



Electrical
tape

MATERIALS

- Warden Robot Kit
- Four gearmotor boards
- 10 feet of 20-gauge red/black zip cord
- One pair alligator clips
- Pololu TReX Jr dual-motor controller
- On/off toggle switch
- Two 12-inch servo extension cables
- Two-channel transmitter/receiver radio-control system
- Four 12-inch male-to-male JST connectors
- Four gearmotor end caps
- 31 1/2-inch-by-6-32 socket-head cap screws
- 31 6-32 nylock nuts
- 12-volt 5 AH gel-cell battery
- 12-volt DC 500 mAh battery charger



INSTRUCTIONS

1 Assemble the Warden Robot Kit according to the Actobotics instructions.

2 Solder a gearmotor board to each motor.

3 Separate the red-and-black wire from the zip cord. Solder a black alligator clip to one black end. Strip and insert the other end into the GND terminal of TReX Jr.

4 Cut the red wire in half. For one half, solder a red alligator clip to one end and connect the other end to the on/off switch. For the other red wire, solder one end to the switch, and strip and insert the opposite end into the positive 12-volt terminal of the TReX Jr.

5 Route the two servo extensions from the CH1 and CH2 headers of TReX Jr to, respectively, the CH2 and CH3 outputs of the R/C receiver.

6 Snip one set of plugs off each JST connector. Strip the ends and plug the remaining JST connectors into the gearmotor boards, reversing their polarity in the rear gearmotors.

7 Twist the stripped ends of the two left motors together, red to red and black to black, and insert the joined ends into the M1 terminals of TReX Jr. Repeat for the right motors, but insert into the M2 terminals.

8 Print the parts of the shovel blade, using the STL files at popsci.com/RCplow. Fasten them to the front bumper with the socket-head cap screws and nylock nuts.

9 Charge the battery, if needed. Mount the on/off switch to the rear bumper, and slip the alligator clips onto the battery terminals.

10 Put battery, wires, and electronics into the main compartment, and apply water-resistant electrical tape over all openings. Turn on the switch, and test the speed control and directional drive of each motor. Now you're ready to kick back and show the snow who's boss.

Meet a Maker

Tiny Home Builder

by
**REBECCA
HARRINGTON**

When Hailey Fort decided she wanted to build a shelter for a local homeless man named Edward, her parents said she had to draw a blueprint first. So the 9-year-old native of Bremerton, Washington, started by planning the 32-square-foot footprint—and then designed a tiny house from the ground up.

Hailey has been building things for most of her life, whether it's helping out her mom, Miranda, with home projects or consulting with her grandfather, who's a contractor. But when it came to constructing Edward's house, she did everything herself (although

her parents did step in to give pointers and help lift heavy materials). Miranda and her husband, Quentin, banned Hailey from using power saws and let her work for only about an hour each day, so the house—which has windows, insulation, and solar panels for electricity—took several months to complete. "If she had her way, she would work all day," Miranda says.

Now that she's finished with Edward's house, Hailey plans to make at least 10 more over the next two years. Her family is coordinating with local churches to find a place to park the shelters, which have wheels for easy transportation. After that, Hailey plans to keep building things. "I want to be an engineer," she says. In the meantime, she hopes other people will help out in their communities: "You can do that by just planting a tree or opening the door for someone."

TIPS FOR BUILDING SMALL

Ryan Mitchell, who lives in a 150-square-foot house and runs the website *The Tiny Life*, shares his tips for tiny-home builders.

- 1 Every hour of building usually takes an hour of research.
- 2 Design the house around the core things you really need to live your life.
- 3 Storage is critical: If every item has its own place, it will be easier to keep the house neat.
- 4 Accidents happen; use tools carefully, and be prepared.
- 5 Your best tool is a chair to sit in—so you can figure out how to overcome any challenges.

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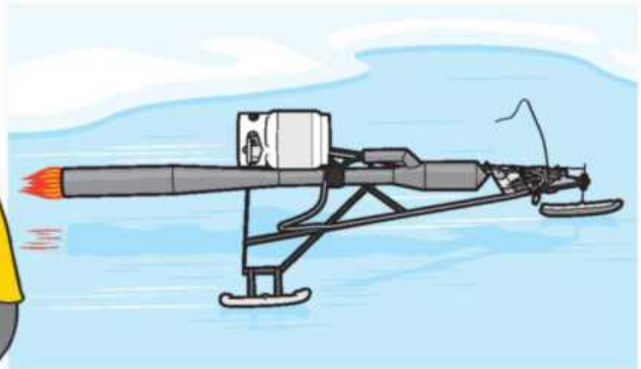
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Theme Building

SNOWBOARD

Entrepreneur Jude Gomila was tired of having to push his snowboard across the flats by foot. To propel himself, he mounted a battery-powered jet engine to his board. First, he 3-D-printed six separate parts and assembled them into the mount. Then he attached a ducted fan engine. "It sounds like 100 vacuum cleaners going off at the same time," Gomila says. "But outdoors, it's actually not that bad." By connecting a handheld controller to the motor, he can gradually increase his speed up to 15 miles per hour.



RC ICE CAR

When Mason Ferlic was a high school senior, his parents gave him a welder. He and his youngest brother, Evan, immediately began using the new tool to build valveless pulse jets. The Ferlics put the engines to good use on the frozen lakes that dot the landscape of their native Minnesota. They attached old ice-skate blades to

a sturdy frame, and then added a jet, a propane fuel tank, and the control system from a remote-controlled car. The resulting RC ice racer zips across the surface at up to 20 miles per hour. Evan says he's surprised it worked as well as it did. "It blew us out of the water," he says. The car can skate for about five minutes straight before running out of fuel.



SNOWBLOWER TRAIN

When winter storms threaten to shut down commuter trains, New York City's Metropolitan Transportation Authority blasts snow off the switches with jet engines. Built and mounted on railroad vehicles by mechanic Olie M. Ericksen, so-called snow jets use old aircraft engines as heating units. Ericksen replaced the original ignition systems with acetylene ones, which use a lower-voltage spark to ignite the fuel. "It actually works much better than the high-voltage spark, especially in colder temperatures," he says. The jets can even blow or melt

ice from the third rail (which provides trains with electric power) with 700- to 900-degree exhaust. Ericksen isn't the first to build snow jets—the oldest one still in use dates back to the 1960s. And some onboard engines are even older: Certain snow trains still use J57s, the first American jet engine to produce more than 10,000 pounds of thrust.

by
ALLIE WILKINSON

Win Winter with These Jet-Powered Projects

Retire the reindeer—and fire up the jet engines. These three vehicles will put your average sleigh to shame.

A Reflective Dashboard for Your Morning Routine

Ditch your Post-it notes for reminders built right into a mirror. Software engineer Hannah Mittelstaedt programmed an old Android tablet to show time, weather, and other information in bright letters on a dark background. Place the device behind a two-way mirror, and only the text will shine through. "Something about brushing your teeth in front of it makes it feel more like the future," she says. Use her open-source program to make your own smart mirror, or modify it to do more—Mittelstaedt's can analyze her face to detect her mood.

by
LYDIA CHAIN

TIME 2 hours

COST \$30

DIFFICULTY ● ● ● ● ●

MATERIALS

- Android smartphone or tablet
- Acrylic two-way mirror
- Pencil
- Scissors
- Black construction paper
- Glue stick
- Double-sided adhesive strips
- Drill
- Hooks or nails



Use an old Android device as the brains for a smart mirror.

INSTRUCTIONS

- 1 Download the Home Mirror application (find the link at popsci.com/smartmirror) and open it on your Android device. Set the screen brightness to maximum.
- 2 Measure and cut the black construction paper to cover the entire back of the mirror, except for where the device will sit and for an extra half-inch around each of its sides.
- 3 Put an even coat of glue on the paper, and stick it to the mirror. Gently adjust its position, and let it dry for at least 15 minutes.
- 4 Cut a strip of paper the height of the device and three times as wide. Glue the edge of the strip to the outside edge of the mirror's uncovered area.
- 5 Put adhesive strips on the side and bottom of the uncovered area. Press the free-hanging strip against the adhesive to form a pocket.
- 6 Ensure no light leaks behind the mirror. Then drill small holes at the top for hooks or nails.
- 7 Slide the Android device into its pocket, hang your mirror, and take a look.

Bookmark

Initial State



Today, more and more devices come with a Web connection. Jamie Bailey created the website Initial State to store and visualize the incredible amount of data these machines can produce. Makers can use the site for simple projects, like graphing the daily change in temperature, or more-complex ones. For example, Bailey's smart kitchen trash can tells the site how full it's getting, and his fridge conveys how many beverages it holds (so he always knows when his nephew steals a beer). "When you start capturing all this data, you realize how alive your house or your apartment really is," he says. DIYers can find tutorials for projects like these on the site—or dream up their own data-based ideas.

by
NICOLE LOU

I Defend My Backyard with a Bottle Bazooka

WARNING: Check your local laws and regulations before firing off a bottle bazooka—and don't aim at innocent bystanders.

I've always wanted my own bazooka, but my neighbors might not look upon that too favorably. So instead, I satisfied my craving with a bazookalike contraption capable of launching plastic bottles clear across my backyard. While it might not be quite on the level of a U.S. Army M72 rocket launcher, my

beverage-bottle bazooka sure does shoot with authority.

The original bazooka was developed to stop tanks during the early stages of World War II. In late 1940, the military had created a new type of grenade that focused its blast into a narrow point of energy capable of penetrating tank armor. But it had a relatively short range. So 2nd Lt. Edward Uhl decided to build a device to keep foot soldiers away from the tanks they were targeting.

After a bit of noodling, Uhl attached a dummy grenade to a rocket and put the rocket in a portable launch tube. The first tests of his device took place on a dock on the Potomac River near the Aberdeen Proving Ground in northern Maryland. The projectile flew straight and far into the river channel, and later, at a mortar shoot-off, Uhl scored a direct hit. A brigadier general nicknamed this rocket-launching gadget a bazooka, after the stovepipe-like musical instrument used by a radio comedian at the time.

DIY-history columnist **WILLIAM GURSTELLE** gives bygone weapons a modern spin

My design for a bazooka looks a lot like the real McCoy. For the barrel, I used a 3-inch-diameter heavy paper tube I found at a local packaging store. My projectile is an uncapped plastic beverage bottle, filled with a mixture of air and evaporated alcohol. I position it in the tube so that the bazooka's trigger—a modified grill igniter—fits inside the bottle. When a spark sets off the alcohol, it forms a hot gas that gushes out of the bottle's mouth, propelling the plastic out of the tube. My bottle bazooka sports a distinctive and tough look. Even better, it packs a heckuva wallop.



Visit popsci.com/bottlebazooka for instructions on making your own.

How a Chicago Doctor Shook Up the Hearing Aid Industry with his Newest Invention

New nearly invisible digital hearing aid breaks price barrier in affordability

Reported by J. Page

Chicago: Board-certified Ear, Nose, & Throat physician Dr. S. Cherukuri has done it once again with his newest invention of a medical-grade, **ALL-DIGITAL**, affordable hearing aid.

This new digital hearing aid is packed with all the features of \$3,500 competitors at a mere fraction of the cost. Now, most people with hearing loss are able to enjoy crystal clear, natural sound—in a crowd, on the phone, in the wind—without suffering through “whistling” and annoying background noise.

New Hearing Aid Outperforms Expensive Competitors

This sleek, lightweight, fully programmed hearing aid is the outgrowth of the digital revolution that is changing our world. While demand for “all things digital” caused most prices to plunge (consider DVD players and computers, which originally sold for thousands of dollars and today can be purchased for less), yet the cost of a digital medical hearing aid remains out of reach.

Dr. Cherukuri knew that many of his patients would benefit but couldn't afford the expense of these new digital hearing aids. Generally they are *not* covered by Medicare and most private health insurance.

The doctor evaluated all the high priced digital hearing aids on the market, broke them down to their base components, and then created his own affordable version—called the MDHearingAid *AIR* for its virtually invisible, lightweight appearance.



Nearly Invisible!

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- ✓ Telecoil setting for use with compatible phones, and looped environments like churches
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Affordable Digital Technology

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FDA Guidance and Consumer Education

The FDA states that only FDA-Registered hearing aids, such as the MDHearingAid *AIR* should be used to help people with hearing loss. Imitation “Personal Sound Amplifiers (PSAPs)” are not a substitute for hearing aids and can, in fact, lead to more damage in your hearing.

The MDHearingAid *AIR* is FDA-Registered. This doctor designed and approved hearing aid comes with a full year's supply of long life batteries. It delivers crisp, clear sound all day long and the soft flexible ear buds are so comfortable you won't realize you're wearing them.

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Can a hearing aid delay or prevent dementia?

A study by Johns Hopkins and National Institute on Aging suggests older individuals with hearing loss are significantly more likely to develop dementia over time than those who retain their hearing. They suggest that an intervention—such as a hearing aid—could delay or prevent dementia by improving hearing!

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“I am hearing things I didn't know I was missing. Really amazing. I'm wearing them all the time” —Linda I., Indiana

“Almost work too well. I am a teacher and hearing much better now” —Lillian B., California

“I have used many expensive hearing aids, some over \$5,000. The AIRs have greatly improved my enjoyment of life” —Som Y., Michigan

“I would definitely recommend them to my patients with hearing loss” —Amy S., Audiologist, Indiana



Drone Racing Takes Off

This past July, Steele Davis walked onto Sacramento's Bonney Field and prepared to steer a drone around a flag-marked track. First he donned a pair of goggles. Then he launched his H-shaped quadcopter and sent it into his signature trick, an inverted yaw spin.

"You flip upside down and then rotate," says Davis, a 25-year-old from Atlanta. "So you're inverted, but you're being forced toward the ground because the props are still spinning."

Davis is one of the pioneers in the sport of first-person-view drone racing. Pilots competing in the races wear goggles that give them a drone's-eye aerial view, streamed from cameras on their machines. The effect is as if they had been miniaturized and placed in tiny drone cockpits.

The sport began as casual races among friends. French model-aircraft association Airgony recorded one of these and posted the video on YouTube a little over a year ago. The footage of drones racing through a forest racked up more than 2 million views. As more FPV drone videos hit the Web, the burgeoning sport grew, culminating

in the first large-scale, organized drone-racing competition: the U.S. National Drone Racing Championships.

Over two days this past summer, 120 FPV pilots from around the world descended on the California State Fair to compete for the fastest five-lap time—and more than \$25,000 in prizes.

by
**ANDREW
ZALESKI**

Davis and eight other pilots also participated in a special freestyle heat. In this category, judges score competitors based on the intricacy and

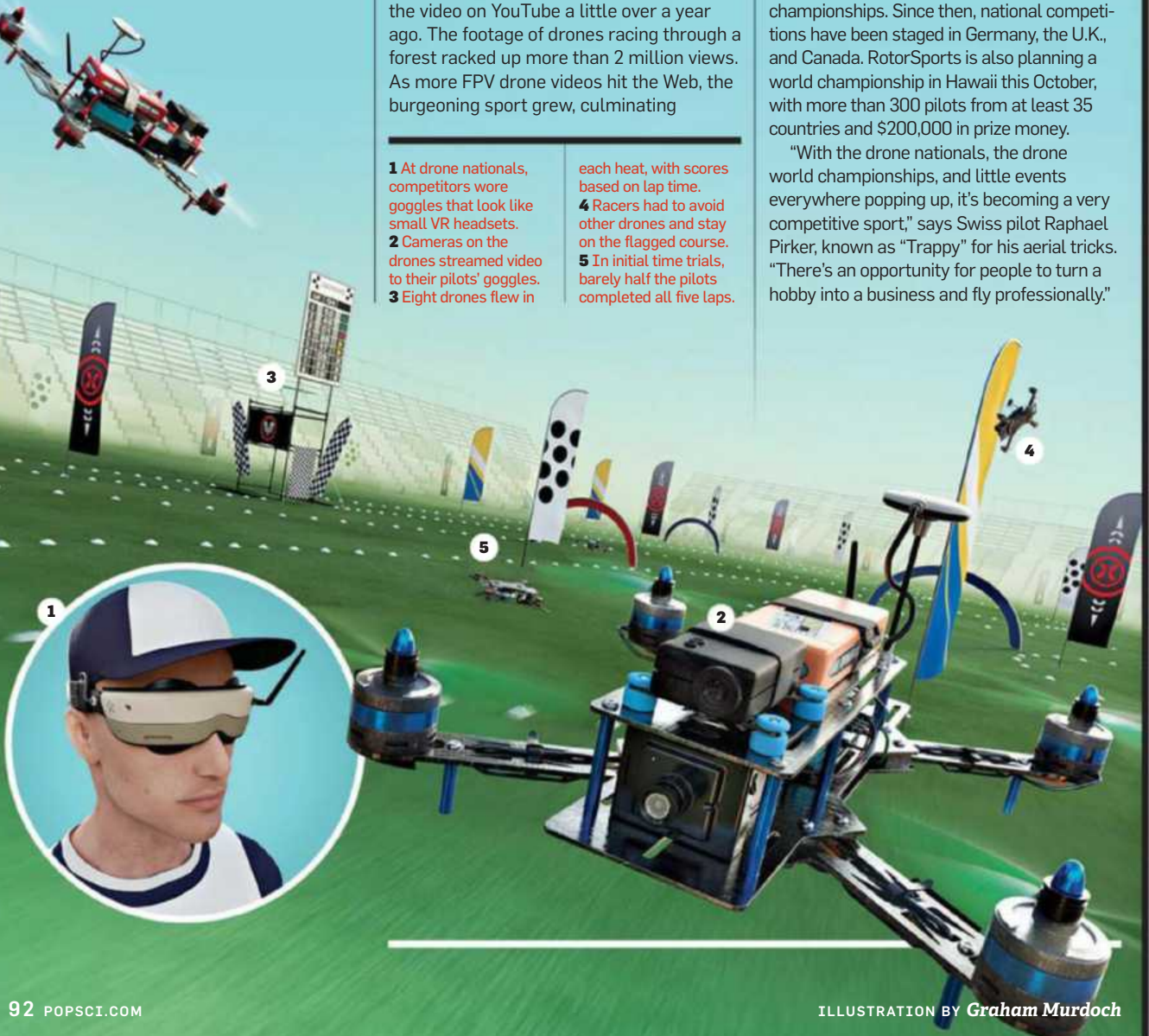
inventiveness of their maneuvers. Davis took second behind Australian Chad Nowak.

"Everybody was racing in different countries, but this was the first official international one that put it on the map," says Scot Refsland, CEO of RotorSports, the California company that organized the U.S. championships. Since then, national competitions have been staged in Germany, the U.K., and Canada. RotorSports is also planning a world championship in Hawaii this October, with more than 300 pilots from at least 35 countries and \$200,000 in prize money.

"With the drone nationals, the drone world championships, and little events everywhere popping up, it's becoming a very competitive sport," says Swiss pilot Raphael Pirker, known as "Trappy" for his aerial tricks. "There's an opportunity for people to turn a hobby into a business and fly professionally."

1 At drone nationals, competitors wore goggles that look like small VR headsets.
2 Cameras on the drones streamed video to their pilots' goggles.
3 Eight drones flew in

each heat, with scores based on lap time.
4 Racers had to avoid other drones and stay on the flagged course.
5 In initial time trials, barely half the pilots completed all five laps.



Choose Life Grow Young with HGH

From the landmark book *Grow Young with HGH* comes the most powerful, over-the-counter health supplement in the history of man. Human growth hormone was first discovered in 1920 and has long been thought by the medical community to be necessary only to stimulate the body to full adult size and therefore unnecessary past the age of 20. Recent studies, however, have overturned this notion completely, discovering instead that the natural decline of Human Growth Hormone (HGH), from ages 21 to 61 (the average age at which there is only a trace left in the body) and is the main reason why the body ages and fails to regenerate itself to its 25 year-old biological age.

Like a picked flower cut from the source, we gradually wilt physically and mentally and become vulnerable to a host of degenerative diseases, that we simply weren't susceptible to in our early adult years.

Modern medical science now regards aging as a disease that is treatable and preventable and that "aging", the disease, is actually a compilation of various diseases and pathologies, from everything, like a rise in blood glucose and pressure to diabetes, skin wrinkling and so on. All of these aging symptoms can be stopped and rolled back by maintaining Growth Hormone levels in

the blood at the same levels HGH existed in the blood when we were 25 years old.

There is a receptor site in almost every cell in the human body for HGH, so its regenerative and healing effects are very comprehensive.

Growth Hormone first synthesized in 1985 under the Reagan Orphan drug act, to treat dwarfism, was quickly recognized to stop aging in its tracks and reverse it to a remarkable degree. Since then, only the lucky and the rich have had access to it at the cost of \$10,000 US per year.

The next big breakthrough was to come in 1997 when a group of doctors and scientists, developed an all-natural source product which would cause your own natural HGH to be released again and do all the remarkable things it did for you in your 20's. Now available to every adult for about the price of a coffee and donut a day.



GHR now available in America, just in time for the aging Baby Boomers and everyone else from age 30 to 90 who doesn't want to age rapidly but would rather stay young, beautiful and healthy all of the time.

The new HGH releasers are winning converts from the synthetic HGH users as well, since GHR is just as effective, is oral instead of self-injectable and is very affordable.

GHR is a natural releaser, has no known side effects, unlike the synthetic version and has no known drug interactions. Progressive doctors admit that this is the direction medicine is seeking to go, to get the body to heal itself instead of employing drugs. GHR is truly a revolutionary paradigm shift in medicine and, like any modern leap frog advance, many others will be left in the dust holding their limited, or useless drugs and remedies.

It is now thought that HGH is so comprehensive in its healing and regenerative powers that it is today, where the computer industry was twenty years ago, that it will displace so many prescription and non-prescription drugs and health remedies that it is staggering to think of.

The president of BIE Health Products stated in a recent interview, I've been waiting for these products since the 70's. We knew they would come, if only we could stay healthy and live long enough to see them! If you want to stay on top of your game, physically and mentally as you age, this product is a boon, especially for the highly skilled professionals who have made large investments in their education, and experience. Also with the failure of Congress to honor our seniors with pharmaceutical coverage policy, it's more important than ever to take pro-active steps to safeguard your health. Continued use of GHR will make a radical difference in your health, HGH is particularly helpful to the elderly who, given a choice, would rather stay independent in their own home, strong, healthy and alert enough to manage their own affairs, exercise and stay involved in their communities. Frank, age 85, walks two miles a day, plays golf, belongs to a dance club for seniors, had a girl friend again and doesn't need Viagra, passed his drivers test and is hardly ever home when we call - GHR delivers.

HGH is known to relieve symptoms of Asthma, Angina, Chronic Fatigue, Constipation, Lower back pain and Sciatica, Cataracts and Macular Degeneration, Menopause, Fibromyalgia, Regular and Diabetic Neuropathy, Hepatitis, helps Kidney Dialysis and Heart and Stroke recovery.

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CODE PSC

Feed Your 3-D Printer Recycled Plastic

If you want to 3-D-print all of your ideas, you'll need to start with a hefty supply of plastic filament—the “ink” used by 3-D printers. Or you could get a ProtoCycler and make your own.

In 2013, Dennon Oosterman and his former classmates Alex Kay and David Joyce grew tired of churning through expensive filament. So they built a machine that could recycle it back into usable form. The \$700 ProtoCycler grinds scrap plastic—such as empty bottles and rejected 3-D-printed models—into digestible pieces, melts it down, extrudes it, and winds it onto a spool. To ensure consistency, a computer-controlled diameter-feedback system uses two cameras to accurately measure the width of the filament.

by
**XAVIER
HARDING**

There are a few drawbacks to recycled plastic. Although the ProtoCycler's

filament starts out with about the same strength as the standard stuff, it gets weaker with each reuse. Reprinting your model too many times might make it brittle and frail. Multicolored plastic also blends like paint. This isn't a problem at first, but eventually your filament will end up brown. None of that is a big deal if you're using the printer to rapidly prototype designs, when quantity matters more than quality. “Anyone can 3-D-print something over and over again until they get it perfect,” Oosterman says.



Tech Support



Q: My truck's been broken into twice. I need help building a security system!
—**HOPEFUL TRUCKER**

A: You might consider building a circuit with our motion trigger and buzzer modules to make a noise when someone moves nearby. If you have an Internet connection in your truck, you can program our cloud module to send you a text message when the motion trigger goes off. You can also include an MP3 module to play the intruder a prerecorded sound or message.
—**ALLISON VANNATTA**
LITTLEBITS REPRESENTATIVE

as told to
STEPH YIN

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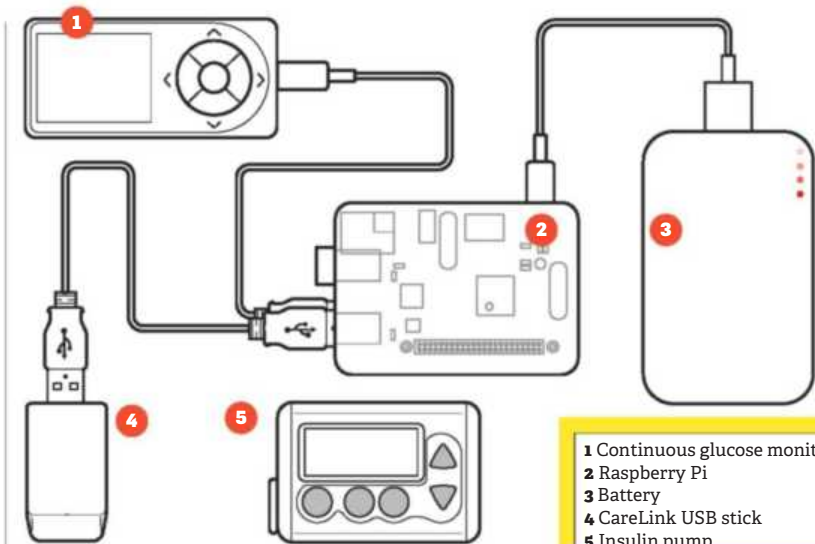
Hacker Medicine

To manage her Type 1 diabetes, digital communications specialist Dana Lewis used to rely on a glucose monitor that beeped when her blood sugar hit an unhealthy level. But she frequently dozed through the alerts. "My life was at risk every night," she says.

So when Lewis first started dating her now-husband, network engineer Scott Leibrand, they developed their own system.

Lewis designed and Leibrand did most of the coding for an algorithm that calculates Lewis' insulin needs based on her monitor's readings. After a year of testing, they loaded the program onto a Raspberry Pi and connected it to a battery,

by
**ANDREW
ROSENBLUM**



- 1 Continuous glucose monitor
- 2 Raspberry Pi
- 3 Battery
- 4 CareLink USB stick
- 5 Insulin pump

1,250,000

Approximate
number of
Americans who
have Type 1
diabetes

the glucose monitor, and a medical USB stick. When Lewis' glucose level is unsafe, the program automatically sends the correct insulin dosage to the USB stick, which wirelessly commands her insulin pump to inject it.

Although FDA rules bar Lewis and Leibrand from publishing full

instructions, they have released a partial codebase and reference design online. "If someone takes the time to understand how diabetes care has to work, they can put all the pieces together," says Leibrand. So far, 15 others have followed suit in hacking their own health.

ILLUSTRATION BY CLINT FORD

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Inventing Sci-Fi Languages

As a college freshman, David J. Peterson became fascinated with languages. He then began inventing his own words and grammar. "It was kind of like crocheting," he says. "Except you can make money with crocheting." Peterson finally hit payday in 2009, when he won a competition to design the Dothraki language for *Game of Thrones*. Soon, he was crafting fictional tongues for TV shows like *Defiance* and *The 100*.

4,000

Number of words in Dothraki, the language of *Game of Thrones*' nomadic warrior tribe

"Hash yer astoe ki Dothraki?"*



How do you start inventing a language?

I separate the process into three distinct branches: sounds, word meanings, and grammar. I usually start with the sound system, which

by
**MATT
GILES**

*Do you speak Dothraki?

affects grammar, and also with nouns. Then I base the language on whatever desire I have for the grammar's shape to take.

In the real world, languages evolve over time. Do yours?

I am creating the language to look as if it evolved in the real world, so it has to have a realistic character to it. But since I am emulating thousands of years of linguistic evolution on paper, it is a monumentally difficult task.

Is there anything you try to consciously avoid?

I don't like articles and verbs. Languages like Russian, which have no definite or indefinite articles, get on fine without them—and that's wonderful.

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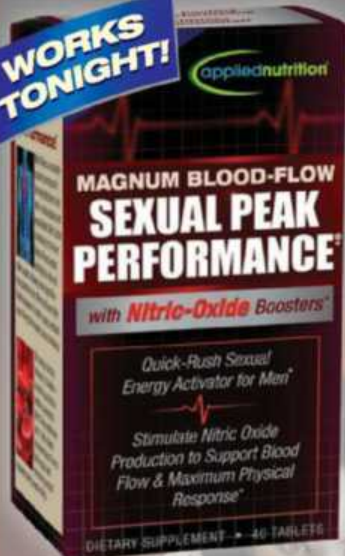
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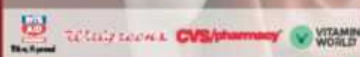
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ANSWERS BY **Daniel Engber**
ILLUSTRATIONS BY **Jason Schneider**

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it to askanything@popsci.com or
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Q: SHOULD I BE FREAKED OUT BY BACKWASH?

Short answer Yes.

A:

The term “backwash,” referring to the mix of beverage and saliva that sloshes back into a shared drink, has been in use only since the mid-1980s. But concerns about its disgusting nature go back centuries. Early Muslim scholars argued over whether the liquid leftover in a vessel after someone has drunk from it—called *su’r* in Arabic—was pure enough to be used for ritual ablutions. These days, we have hard science to settle that ancient debate.

Sunny Jung of Virginia Tech, who studies fluid mechanics in biological systems, explains that, in general, animals take in water in one of two ways: They either lap it up, like a dog, or they use a suction mechanism. Humans (and mosquitoes and elephants) fall into the latter camp. It’s a pretty efficient mechanism, but it can’t ensure that all the fluid will be contained: “There’s [always] some small amount of backflow,” Jung says.

There’s also evidence that backwash contains bacteria, and that sharing drinks can spread disease. In 2007, for example, epidemiologists began a study of pneumococcal pneumonia among young recruits in the Israeli Defense Forces. During six months of basic training, about one-third of recruits acquired the bacteria. Those who said they “always” or “usually” drank from shared bottles were at more than twice the risk of the contagion. It’s hard to know whether pneumococci were surfing a wave of backwash, or if the germs merely settled on the spout. Either way, it’s gross.



Q: DO PEOPLE WHO GROW UP IN THE ARCTIC SEE BETTER IN THE DARK?

Short answer They definitely get the blues.

A:

People who live north of the Arctic Circle experience two months each year with no direct sunlight. During the dark winters, the only natural illumination people experience is twilight, which tends to have a bluish color. So in 2007, cognitive neuropsychology specialist Bruno Laeng set out to see how this might affect the vision of these northernmost inhabitants.

Laeng and his colleagues gathered about 250 people, mostly undergraduates from the Arctic University of Norway (where Laeng, now at the University of Oslo, was a professor at the time), and split them into two groups: those who were born above the Arctic Circle and those born below it. Both groups took a test measuring color discrimination, in which they had to arrange more than 85 color tabs according to the progression in their hues. Those born in polar regions made more mistakes arranging the yellow-green and green tabs, but far fewer mistakes arranging the blueish ones. (Perhaps not surprisingly, the prevalence of red-green color blindness is higher in populations that live farther from the equator.)

Language also supports Laeng's findings: Ohio State University psychologist Angela Brown looked at dictionaries for various populations—more than 450 languages in all—to see which ones had distinct words for the color “blue.” She found that the closer people lived to the poles, the more they distinguished between the blues.

K-band false alarms driving you nuts?

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Q: WHY DO I FEEL LIKE SOMEONE'S WATCHING ME?

Short answer Your brain is likely reverse-engineering a reason.

A:

In 1898, a prominent Cornell psychologist named Edward Titchener used a few simple tests on his students to prove that the “feeling of being stared at” was a product of neurosis. He became convinced it was. But we’ve learned since there are likely more than just panicky feelings at play.

The “stared at” paranoia could arise from several factors, one of which is confirmation

bias. You remember those moments you turned around and saw someone staring at you, but you’ll forget the times when this was not the case. Or someone might be watching—just not with the intention you think: A sudden movement could have triggered an unintended glance from a stranger. And never discount the role of an overactive imagination. For instance, you might hear a sound behind you that’s too quiet to enter consciousness

but loud enough to activate the fear circuits in the amygdala—the brain region primarily responsible for memory processing, decision-making, and emotional reactions. Then your brain constructs a story to explain it. “For some people the feeling itself is so compelling that they have to explain it as something real,” says University of Waterloo psychology professor emeritus

James Allan Cheyne.

This same mechanism could be at work, on overdrive, in the minds of diagnosed paranoids, who experience delusions, hallucinations, and disruptions of typical emotions and thoughts. “Most pathologies are extreme conditions,” Cheyne says. “They tend to be exaggerated forms of something that we experience all the time.”



Q: WHICH IS MORE POWERFUL: A GIANT MICROSCOPE OR A GIANT TELESCOPE?

Short answer The edge is microscopic.

A:

The Scanning Transmission Electron Holography Microscope stands 15 feet tall and weighs 14,000 pounds. “It’s such a powerful machine,” says Rodney Herring, who runs the microscope facility at the University of Victoria in Vancouver. It can image at an unprocessed resolution of 35 trillionths of a meter, making it more powerful than any other microscope in the world. And any telescope too.

Microscopes like Herring’s take images using electrons, which have a wavelength five orders of magnitude smaller than that



of light. Telescopes can’t use the same approach, because electrons from a far-off source would be deflected or absorbed before they made their way to Earth. “Electrons don’t reach us, but light does,” says Herring, which is one reason that “we can see a lot better looking down at small things than we can looking out at big things.”

Microscopists can also manipulate their samples. According to Mark Neil, an optical physicist at Imperial College London, illuminating a sample with a pair of lasers can improve the resolution of a normal

microscope, from 300 nanometers to 10 nm. Electron microscopes like Herring’s push that down even farther, into the atomic scale.

It’s hard to find a comparable measure for a giant telescope. Astronomers are less concerned with linear resolution than they are with angular resolution, measured in arc-seconds (1/3,600 of a degree). The Hubble Space Telescope, for example, can take images less than 0.1 arc-seconds. The European Extremely Large Telescope—currently under construction on a Chilean mountaintop—will have an angular resolution of 0.01 arc-seconds or better.

To draw an accurate comparison between telescopes and microscopes, we should think of them in terms of the unaided human eye. Neil says a person with normal vision is able to perceive objects at a linear resolution of about 25,000 nm and an angular resolution of about 60 arc-seconds. So the best microscopes take us from 25,000 nm to 0.035 nm—a 714,000-fold improvement. The best telescopes, on the other hand, can push our vision only from 60 arc-seconds to 0.01 arc-seconds—a 6,000-fold improvement. **PS**



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tried to enrich himself by debunking the discovery at the expense of the University which resulted in 100's of letters and phone calls demonizing the man until they forced him to state: "They don't endorse him!". They also received complaints from our customers that included Sloan Kettering Oncologists and scientists at Lawrence Livermore including the top scientist at the Los Alamos Nuclear Lab (with so many degrees after his name he needs a fold-out calling card) who bought our E5 machine and called Jon Spokes, the Advertising Manager at The Washington Times National Weekly "I am embarrassed," he said, "to admit this, but John Ellis HAS changed the Hydrogen Bond Angle in water. I wish I owned his patents!"

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old reading a book about the ancients in the Mellon Library at The Choate School that said: "Rapidly heating and cooling water produces mystical qualities". He never thought any more about it until Art Linkletter sent an M.D. to Hunza to see why they lived to advanced age in good health. He found that the people that lived the longest collected water during the day from pools of water in glaciers at the top of the mountains that later froze at night. However, the doctor was fooled into thinking this water was like "distilled water" which it isn't!! Ordinary distilled water has a HBA of ONLY 101 DEGREES which produced the WORST measurable Blood Flow (above)! Although a 104 HBA is an AVERAGE, glacier water probably has more 108 (HBA) molecules even if it's heated/cooled only once daily. This gave John Ellis the idea to rapidly heat and cool water not once but 100's of times/gallon TO SEE IF IT WOULD INCREASE THE HBA AND INCREASE THE HEALTH BENEFITS EVEN MORE and it HAS... on any subject you can name! Like the Washington Post Investigative Article also says: "The curative power results from the movements of water between two metal tanks!" which is the result of our little countertop stainless steel machine! However, all claims are made for the WATER not a "machine device" adjusted at the factory. Thirteen Patents, 332 FDA Tests

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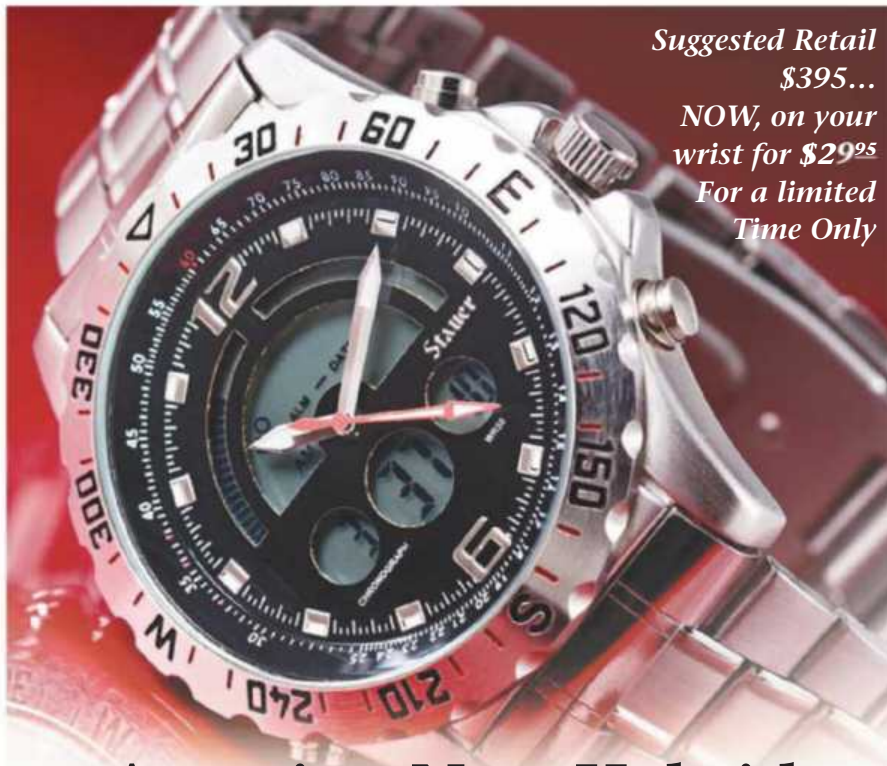
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In a profoundly urbanized vision of the future, science-fiction artist John Harris imagines a city navigated by foot, with skyscrapers connected by viaduct. Harris says he was inspired by Canadian cities that planned to enclose walkways between their buildings to avoid the winter weather. The dense cityscape is an enduring vision, he thinks, "because there's a presumption that we'll become such an overcrowded planet that there won't be any room for greenery." A committed ruralist who lives in the English countryside, Harris also explores the idea of adapting organic structures for human habitation in his work—such as his mushroom city, which we featured in our August 2015 issue.

by
**KATIE
PEEK**

Dispatch from the Future is a series that imagines—through images and words—how humanity will live in the decades and centuries to come.

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